ONR Europe Reports

92-10-R

Affordable Environmental Technology:

Preparing For the 21st Century

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20 December 1992

Office of Naval Research European Office

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Affordable Environmental Technology: Preparing for the 21st Century

Views of Activity in the Federal Republic of Germany, United Kingdom, Israel, the Commission of European Communities and the NATO Committee on the Challenges of Modern Society Brussels, Belgium

by Paul Schatzberg. Dr. Schatzberg wrote this report in the capacity of a visiting liaison scientist in the area of environmental sciences for the Office of Naval Research European Office while on leave from the Carderock Division, Naval Surface Warfare Center (formerly David Taylor Research Center) where he is a scientist in the chemical and physical processes department.

INTRODUCTION

An initial effort to assess environmental research in other countries was undertaken by the Office of Naval Research European Office (ONR Europe). Serving as the first Liaison Scientist in this initiative, I made selected visits to the United Kingdom (U.K.), the Federal Republic of Germany (FRG), the State of Israel, NATO, and the Commission of European Communities, Brussels, Belgium. Results from these visits are described in this report, including conclusions and recommendations. Results are presented as specific environmental topics such as hydrocarbon bioremediation, groundwater treatment, ordnance demilitarization, marine antifouling control, pollution prevention, with reference to existing Navy requirements and research where relevant.

Since the Industrial Revolution, rapid population growth, urbanization, and industrialization have combined to produce sustained environmental insult. During the second half of this century, a geometric increase in environmental legislation (see Fig. 1) and the consequent regulations in the developed nations have failed to reverse this trend, except in special isolated, but noteworthy cases. Recent revelations of the consequences of unregulated industrial activity in Eastern Europe have dramatically demonstrated the value of environmental regulations in sharply reducing the extent of the damage. Developing nations, striving to achieve the standard of life enjoyed by industrialized countries, are perhaps prepared to repeat the mistakes of recent history. It remains a technical challenge for the industrialized nations to provide the knowledge needed to reverse this global trend. However, the increasing cost to achieve this reversal appears to be economically, and therefore politically difficult, if not unattainable.

Research and development (R&D) has the potential for providing the leverage leading to processes that will achieve affordable cleanup of past, and prevent future environmental insult. As a result, there has been an increase in environmental R&D worldwide with little coordination to avoid duplication of effort, despite the fact that national and international symposia on environmental R&D abound.

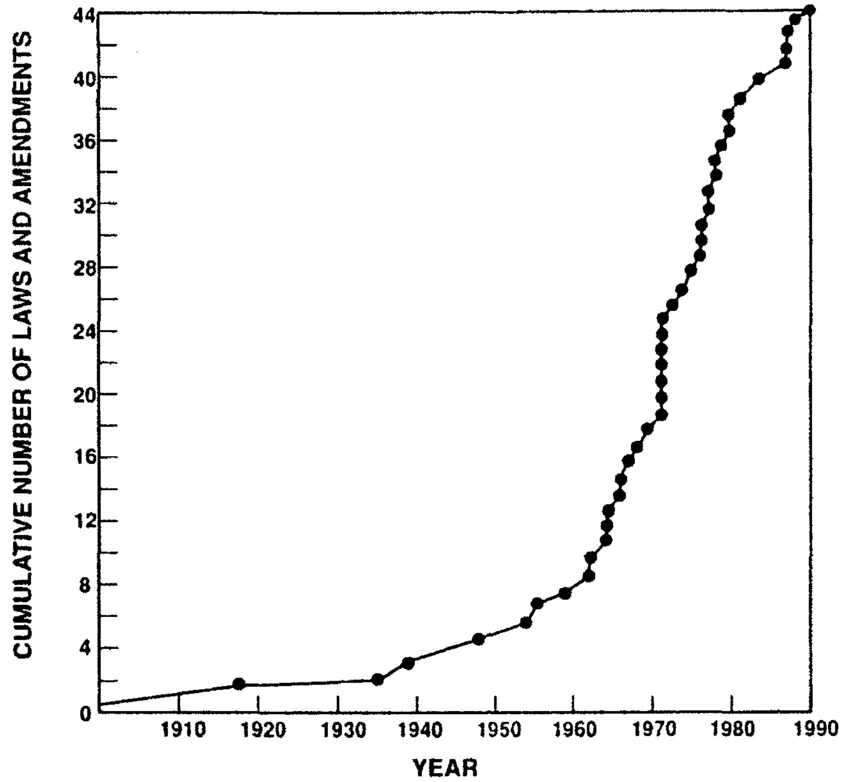

Figure 1. Environmental legislation enacted in the United States.

Academic research, where many skilled investigators are found, has tended to emphasize development of diagnostic methods, such as measurement of pollutants at increasingly lower and lower concentrations, the fate and effect of pollutants, numerical modeling of pollution in air, water, and ground, and more refined laboratory techniques to measure biological response, as well as the development of genetically engineered microorganisms to biodegrade toxic organics. Less effort has been spent on modifying industrial processes that emphasize recycling, substitution of non-hazardous materials for those that lead to hazardous waste generation and demonstrating the economic benefits of pollution prevention. Thus, there well may be opportunities for more effort by academic researchers for research which could be of help in demonstrating and implementing socially valuable results at affordable costs.

Military organizations are in an interesting position to facilitate bringing about this transition. Not only do we have many of the industrial operations generating hazardous wastes, as does the private sector, but we also have large quantities of extremely hazardous energetic and toxic materials which must be disposed, either because they have exceeded shelf life or because they are no longer needed. Furthermore, because of the highly technical nature of modern warfare, we have significant corporate technical capabilities, in-house as well as out of house, in terms of equipment and very skilled personnel that could be effective in environmental technology.

Prudent R&D planning needs to include consideration of research results in other countries. Technology interactions between the Department of Defense (DoD) and several countries are currently in place in different technologies. Recently, negotiations have begun to include environmental research among those activities. Congress in the DoD Appropriations Act of 1992 (Public Law 102-172), encourages the DoD to do more to capitalize on the technological and manufacturing know-how of our NATO and non-NATO allies. Senate-House conferees support "the Senate provision mandating the continuance of the Allied Cooperation Enhancement Studies begun last year (1991). The conferees are encouraged by the preliminary results of this effort which has identified a broad range of emerging and enabling technology initiatives of potential benefit to United States security and the enhancement of our defense industrial base. The inclusion of language for two new studies in the areas of environmental and critical technologies cooperation underscores the conferees belief that the United States-Israel partnership in research and development (R&D) is a powerful tool for advancing the industrial competitiveness and economic vitality of both nations."

In preparation for this, it is opportune to determine the nature, relevance and quality of foreign environmental research. This can be done initially by direct contact through visits to research institutes, universities, and government agencies. Subsequently, some opportunities for cooperative research in the form of joint projects might result

NAVY ENVIRONMENTAL TECHNOLOGY REQUIREMENTS

All Navy environmental technology requirements are based on two corporate goals promulgated by the Chief of Naval Operations (CNO):

1. The environmentally-sound ship of the 21st century will have full access to all global waters, including harbors and estuaries without being constrained by local, regional, national, and international environmental regulations (CNO letter 3/13/89). and
2. Navy industrial shoreside facilities of the 21st century will not release hazardous wastes to the environment (CNO letter 3/30/89).

Recent efforts by the Office of the Chief of Naval Research (OCNR) and the appropriate Army and Air Force counterparts were aimed at demonstrating to the Office of the Secretary of Defense (OSD) and Congress that perceived duplication of effort in Science and Technology (S&T) is being replaced by mutually supportive efforts. This has been institutionalized as Project Reliance, and involves some 30 areas of technology including environmental quality. Accordingly, all environmental quality S&T for FY 93 has been jointly planned by the three services for the first time. Furthermore, all services have jointly prepared an environmental quality R&D requirements document. This document provides a detailed, line item outline of needs which must be addressed. A condensed version of this outline is shown in Appendix A to provide some scope to the extent of these requirements. The DoD requirements "rest" on four broad areas designated "pillars." There are over 400 line items of which 50 percent are of direct interest to the Navy. Results of the environmental technology research visits described in this report fall primarily under Pillar 1 Cleanup, Pillar 2 Compliance, and Pillar 3 Pollution Prevention.

The assessment of work in environmental technology abroad will be presented below. It should be recognized that this is an initial effort focussing on selected programs.

ENVIRONMENTAL BIOTECHNOLOGY

Biological elimination of environmental pollutants and biosafety in biotechnology are the two major themes of the environmental biotechnology research program at the Institute for Biotechnology Research (GBF = Gesellschaft für Biotechnologische Forschung mbH) in Braunschweig-Stoeckheim. The first theme is lead by Dr. Kenneth N. Timmis, head of the Department of Microbiology. Environmental biotechnology at the GBF is multidisciplinary and embraces microbiology, genetics, bio-, immuno-, and analytical chemistry, ecology, biochemical engineering and modeling, and involves three of the four research departments of the GBF: Microbiology, Biochemical Engineering (Molecular Biology), and Enzyme Technology. Approximately 70 scientists, students, and technicians are dedicated to environmental biotechnology which is the second largest of the four research priority programs of the Institute. Although the GBF general management is industrially oriented, high risk research is encouraged. Such research is supported 90 percent by the German Ministry for Research and Technology. The environmental biotechnology program of the GBF is based on a network of collaborations involving not only the internal efforts, but also a number of important national and international cooperations.

The emphasis in the environmental biology group is clearly on molecular biology leading to the development of genetically engineered microorganisms (GEMs) to degrade anthropogenic toxic organics that are resistant to indigenous microorganisms. Such pollutants are heavily chlorinated hydrocarbons like the polychlorinated biphenyls (PCBs), as well as dioxins, dibenzofurans, and perhaps trichlorethylene (TCE); the latter is an effective, multipurpose solvent which, due to poor disposal practices, has extensively contaminated subsoil areas and threatened water supplies. It is a carcinogen. The U.S. Air Force has devoted considerable effort to identifying and culturing natural microorganisms to provide *in situ* biodegradation of TCE-contaminated subsoil, with some measure of success so far, in laboratory experiments. Heavily chlorinated hydrocarbons are only partially dechlorinated in the environment. Therefore, PCB-contaminated soils are currently detoxified by a thermal process developed by the EPA, using sodium bicarbonate to dechlorinate PCBs. This process is being used by the Navy to clean a PCB-contaminated site in Guam. It is effective, but since it involves moving and heating soil, it is labor- and energy-intensive and therefore relatively expensive. Detoxification of PCBs by natural organisms requires both anaerobes and aerobes. Since this involves two conditions which cannot exist together, it must be conducted in successive bioreactors. Clearly, an *in situ* process would be substantially more cost effective. But this involves developing GEMs. The staff at GBF is fully aware that the opposition to using GEMs in the field is even more severe in the FRG than it is in the U.S. Nevertheless, there is a substantial effort underway in this growing and scientifically challenging area at GBF.

Doctor Timmis recognizes the problem of using GEMs in the environment and, where applicable, recommends indigenous microorganisms be used *in situ* or in bioreactors. However, he has organized his research strategy toward those pollutants which are resistant to indigenous microorganisms, requiring the application of molecular biology; that is, for those very toxic pollutants for which there is no choice but to use GEMs. The goals of his program are to design microorganisms or consortia of microorganisms that rapidly and completely degrade environmental pollutants, or that effectively concentrate heavy metals (mercury), and with these strains to produce efficient pollutant removal processes, both contained (bioreactor) and non-contained (*in situ* bioremediation).

The principal goal in genetically modifying an organism for a biotechnical application is good performance in the target setting. If the target setting is a bioreactor in which all relevant parameters

are precisely controlled, then these may be adjusted to maintain the performance achieved by the genetic modification and further genetic manipulation may not be necessary. On the other hand, if the target setting is a partially or entirely open site (crop, aquifer, contaminated field, waste dump), where prevailing conditions cannot be controlled, then adequate performance of the strain may necessitate specific genetic manipulations that compensate for some negative influences of critical environmental parameters. What this means is that aside from the serious public, and therefore government apprehensions in using GEMs, there are several technical challenges in their effective *in situ* application. One is loss of the utility of the organism because the genes which determine the desired properties are carried on plasmid vectors which are not stable in the environment. Thus, the desired performance is lost. The other is that GEMs generally do not have a sufficiently strong physiology to survive in the natural (hostile) environment. The *in situ* biodegradation of subsurface heavy hydrocarbons at an abandoned coal-to-gas conversion site being investigated by the University of Karlsruhe and described later, occurs under a condition of near starvation of the indigenous microorganisms, and little biomass is formed.

A third problem has to do with risk assessment, or the environmental predictability of the GEMs. This is related to the stability of the GEMs and their propensity for lateral transfer of their gene codes to indigenous microorganisms. This gene transfer potential feeds public fears that a new "killer superbug" will be created in nature and that this organism will be pathological to animals and humans. The research strategy to deal with these problems is based on moving away from plasmid vectors and using transposons, although the majority of GEMs are today based on plasmids. Doctor Timmis maintains that these vectors enable bacteria to be constructed that exhibit increased predictability with respect to the expression (regeneration), stability, and transferability of their "new" genetic information.

The research projects underway all concern genetic engineering, including microcosm and macrocosm studies to demonstrate that the GEMs survive and continue to function. Three papers authored at GBF on the survival and function of a genetically engineered pseudomonad in aquatic sediment microcosms were published in the April 1992 issue of Applied and Environmental Microbiology. This is of potential interest as the U.S. Navy is beginning to investigate the problem of sediment disposal from harbor dredging operations with an Office of Naval Technology (ONT)-funded effort in FY 93. These sediments have accumulated toxic organic and inorganic (heavy metals) materials for decades. In those harbors where there is little freshwater inflow and there is little tidal flux (e.g., San Diego), sediment disposal may be a serious problem. Ocean disposal is preferred, but sediments often do not pass the rigorous biological tests required. Land disposal follows, but this is increasingly expensive as the availability of hazardous waste disposal sites decreases. Processing dredged sediments in bioreactors until they can be disposed in the ocean may be a viable solution and under those controlled conditions GEMs may find useful application, but only if natural microorganisms are ineffective.

Doctor Timmis has proposed the European Community (EC) fund a broad environmental biotechnology science program, extending over a four year period, requiring about 240-360 man years, involving several European countries (a minimum of two is required by EC policy), and costing 20-30 million ECU (ECU = $1.35). This is proposed under the so-called Framework IV designation. The EC-Framework research programs are designed to strengthen the competitive position of Europe in the world economy. The argument is made in the proposal, that increased economic growth, has led to an increased load of emissions on the environment, and that the limits of such exploitation have been reached! Therefore, further economic growth will be intimately

connected to the ability to develop technologies which will eliminate or significantly reduce hazardous emissions. Thus, a shift is required from environmental exploitation to environmental partnership and from short-term growth to sustainable development.

While it is not argued, in the proposal, that biotechnological processes are the only means to solve the environmental problems, biotechnology is proposed as offering a wide variety of applications and solutions, and therefore biotechnology offers the means to help achieve the goal of sustainable growth. Two broad categories of research are proposed:

- **Intensive Technology.** Compact, completely closed bioreactors, which can be built on site at or near the source of emissions are needed, because industrial operations generally occur in highly populated areas where there is little space and tight regulations for safety are in force. These processes have treatment times of hours and area requirements of square meters. Examples of such high rate processes are fluidized bed reactors (aerobic and anaerobic); anaerobic air-lift reactors; deep shaft "Turm" (tower) biology; biofilters for odor removal from air; active sludge water treatment; and rotating disc contactor.

- **Extensive Technology**. Restoration of damaged environmental systems such as lakes, surface and subsoil, sediment, and groundwater is needed. The amount of material to be treated is huge, encompassing millions of cubic meters; consequently, extensive technology needs to be applied such as land farming, composting, *in situ* soil treatment, pond treatment of wastewater, waste water irrigation, and bioleaching.

The proposal points out that nearly all of these intensive and extensive processes have already been developed in a semi-empirical way, without much attention to the basic mechanisms, micro-organisms, and complications. This has led to the situation that:

- A substantial body of empirical knowledge concerning technological and operational problems is available
- Nearly always several expensive pilot studies of various technologies are required to determine the most acceptable treatment process for a specific problem
- Nevertheless, a substantial number of failures in application of these technologies has occurred. This is due to the lack of knowledge about the underlying transport and microbial mechanisms
- Processes sometimes work or don't work for unknown reasons.

What Dr. Timmis has proposed, therefore, is that research in Environmental Biotechnology should concentrate on:

- Improvement of existing technologies based on a much better understanding of the microbial and transport mechanisms involved
- Development of new technologies based on understanding mechanisms
- Integrated research in a multidisciplinary way where these technologies are studied under practical conditions, aiming for practical application
- Mathematical modeling of the integrated process to provide the tools for design of installations in specific applications.

This proposal to the EC promises the following benefits for European industry:

- Continued economic growth in a sustainable way because appropriate technology is available (i.e., will become available) to deal with emissions
- New economic activities (opportunities) due to the development and application of these processes
- The developed technology will lead to applications, and hence profits, outside of Europe. This program will therefore strengthen the economic position of European industry
- In performing this research program a network of expertise and highly trained people becomes available and the best information is exchanged more efficiently.

The proposal to the EC is extensive and far reaching. The thrust of the current research at GBF is genetic engineering, and a persuasive argument is made for the application of GEMs in solving serious environmental contamination problems that are refractory to natural microorganisms due to the presence of synthetic materials like PCBs. That is not to say that the GBF proposal to the EC is solely dependent on the use of GEMs.

There was considerable interest at GBF in the current ONT-funded effort in enzymatic paint stripping, and a subsequent telephone call requested additional information. The people contacted at GBF are highly skilled and experienced in molecular biology. They could help the Navy in the enzymatic paint stripping project.

Discussion and Analysis

The structure and argument of the GBF proposal to the EC illustrates the tension between science and technology, between the flask and the field. The fundamental argument of the GBF proposal is, simply put, that we often don't know what we're doing in environmental biotechnology; therefore, a substantial effort in scientific research is justified in order to establish a firm foundation of knowledge upon which applicable technology can be built. Examples of the substantial numbers of failures in application are not provided nor their causal link to insufficient fundamental knowledge. Failures have occurred in hydrocarbon fuel bioremediation, but due to haste working toward progress. Expensive pilot studies are needed because the user community will not accept an emerging technology without field performance data, an economic analysis that can be scaled, and a risk and liability analysis. No amount of scientific knowledge and numerical modeling based on that knowledge will overcome the need for such pilot studies. The argument for a better fundamental understanding of biodegradable mechanisms is primarily directed at pollutants that are very toxic, either do not biodegrade at all or too slowly in nature, and may form toxic byproducts. Examples are trichlorethylene, polychlorinated biphenyls, and dioxin. However, the argument for a better fundamental understanding of environmental biodegradation is often not so tightly delimited, particularly by the academic community.

Last year, the U.S. EPA convened a group of scientists to determine what research needs to be done to advance the application of biodegradation. I was invited to participate. The chairman of this workshop who was from a university, announced he did not want a professor's "wish list," but needed a research program that could yield practical results in 2 to 3 years, otherwise biodegradation would lose out to other technologies. This instruction was received in silence since many of the participants were from universities. The result of the workshop was a long "wish list." The EPA was not prepared to fund this research, but asked many government agencies to participate. From a

user's point of view, such a list of research needs for biodegradation can only lower confidence in this method and delay its application until the research is completed. In apparent contradiction to the long list of bioremediation research needs its workshop produced, the EPA is sponsoring 140 site bioremediation cleanup efforts[1] This discussion does not suggest that fundamental knowledge and understanding is not needed. However, there already exists a lot of such fundamental knowledge. The GBF has proposed an extensive research effort lasting 4 years. It is a strong proposal. The EC support decision will probably not be decided until next year, and then probably not at the level requested. Nevertheless, Dr. Timmis is determined to establish a network of investigators in Europe and the U.S. to share and advance environmental biotechnology.

The next section illustrates that university field research, addressing process variables and proceeding empirically can yield applicable results without full understanding of fundamental mechanisms. That is to say that fundamental knowledge can be applied empirically.

IN SITU BIOREMEDIATION OF SUBSOIL HYDROCARBON CONTAMINATION

There are thousands of military sites in the U.S. contaminated by hydrocarbon fuels as a result of long-term, chronic leakage from corrosion-damaged storage tanks and fuel lines. The fuel components of greatest concern are benzene, ethylbenzene, toluene, and xylene, known as BETX. These aromatics are very toxic, benzene is a known carcinogen. They are relatively soluble in water; at least three orders of magnitude greater than saturated, non-aromatic hydrocarbons of equivalent carbon number. Polynuclear aromatic hydrocarbons (PAHs), present in jet fuel as naphthalenes are also of growing concern. Spilled fuel is gradually dispersed as it percolates through the soil by gravity and hydraulic pressure from precipitation. Most local regulatory agencies simply want the hydrocarbons removed down to approximately 100 ppm, although some are content with a significant decline in the BETX. The most affordable method for removing the dispersed hydrocarbons is by *in situ* biodegradation. Since hydrocarbons are distinct from such man-made materials as PCBs, mixed cultures of indigenous microorganisms are capable of biodegrading them if sufficient oxygen, or other electron-acceptor, is available. If oxygen is supplied and macro-nutrients and micro-nutrients when needed, biodegradation quickly reduces the hydrocarbon content in the soil.

Extensive research by the Air Force and the EPA as well as by the Navy has demonstrated that soil bioventing is an effective method of enhanced *in situ* biodegradation. The Air Force is primarily interested in JP-4 and the Navy in JP-5 bioremediation. The railroad industry and harbor installations, have been storing diesel fuel, and are consequently faced with bioremediating that fuel.

After the conversion to natural gas in the FRG, former coal gasification plant sites were found to be heavily contaminated with high molecular weight hydrocarbons, including large amounts of toxic PAHs. These sites represent a worse case of hydrocarbon-contaminated subsoil than any DoD sites contaminated with distillate fuels like JP-4, JP-5, and diesel fuel. Consequently, research results of *in situ* bioremediation of a former coal gasification site using indigenous microorganisms are directly applicable to current demonstration efforts by the Navy and Air Force. Such a site was visited in Karlsruhe. The effort is supported by several organizations: 1) the Federal Ministry of Research and Technology, 2) the Federal Ministry of Environmental Protection, 3) the State Government of Baden-Wuertemberg, 4) the Municipal Government of Karlsruhe, 5) the Technical University of Karlsruhe, and 6) the Project for Wastewater-Contaminated Ground.

Research at this site is being conducted by Professor Gudelhus, Dr.-Ing. Jerzy Swinianski, and Biologist Ms. H. Wuerdemann, all of the Technical University of Karlsruhe and consultant Dr. Nils-Christian Lund. They constitute an experienced team of professionals, encompassing the disciplines of chemical engineering, soil mechanics, and microbiology. The test site consists of two rectangular fields (each 9 × 15 meters) with contamination extending down to approximately 10 m. The field is separated from the surrounding area by walls. These walls end at 17 m depth in clay soil. Prior to installation of the walls, 4000 m^3 of soil and 350 m^3 of concrete, present as fill material, were removed, the concrete broken, mixed with the excavated soil and returned to the site. The average permeability (hydraulic conductivity) is good at 10^{-3}cm/s and extends to approximately 17 m where relatively impermeable clay soil begins. In addition to the field demonstration experiments, pilot plant and smaller scale laboratory experiments under carefully controlled conditions are underway at the Department of Soil Mechanics and Foundation Engineering, University of Karlsruhe.

The procedure at the field demonstration site consists of a gallery of 16 perforated air tubes installed to a depth of 10 m to provide horizontal air flow. Air is pumped into the soil from six of these tubes, while the remainder are used to withdraw the used air which is cleaned by activated carbon. A flow of percolated water is provided by a surface sprinkling system. This water is recovered by wells, treated and reused, at which time inorganic nutrients (ammonia and phosphate) are added and the pH is maintained at 7. Loss of hydrocarbons through evaporation and water solubility is negligible due to the low volatility and water solubility of the contaminants. The procedure of providing oxygen (3 kg per kg carbon) by air flow is now called soil bioventing in the U.S. Bioventing for bioremediation of more volatile hydrocarbons like jet fuel controls the flow of air to avoid removal by venting into the atmosphere. This process is ready in the U.S. for full scale demonstration by the Air Force.

The test site is almost completely automated, requiring minimal operator involvement once an experiment has begun. Data collection is automatic through a modem, the data is accessible for recording and interpretation at distant locations. Oxygen and carbon dioxide is determined to provide a measure of microbiological activity. Soil samples are taken to determine the nature and quantity of hydrocarbons present. Several controllable variables for potentially optimizing the metabolic process of bioremediation are being investigated. These are, introducing ozone into the air stream, raising the soil temperature by adding heated water, applying biosurfactants and desorbing agents to make the hydrocarbons more bioavailable, and providing intermittent hydraulic shocks to the soil to counteract the heterogeneous nature of the soil and contaminant. Laboratory experiments can also be expected to provide information on the mechanism of bioremediation, because it is possible to conduct experiments with much better control of independent variables.

Results so far show the following:

- Aerobic mineralization of high molecular weight hydrocarbons, including PAHs occurs, with a reduction so far of approximately 1000 kg, based on CO_2 and O_2 measurements. This represents a reduction in soil contaminants of 20 percent to 50 percent after 340 days of operation.
- Complete mineralization of hydrocarbons is demonstrated by the respiration quotient (RQ factor), which is the relationship between CO_2 production and O_2 consumption, and ranges from 0.6 to 0.85. After 340 days, the average RQ factor at the field site was 0.66; however, corrections based on supportable CO_2 loss estimates, brought the RQ factor to 0.75.

- Elevation of soil temperature by heating the percolation water to 40°C in the laboratory pilot operation, demonstrated an increase in CO_2 production which peaked at 38°C, showing a rapid decline thereafter. Temperature measurements at the field site showed that the subsoil is a good insulator, so that the addition of heated percolation water can be done intermittently. Applying heat in this fashion would be particularly useful for contaminated subsoil in cold regions.

- Introducing O_3 into the air stream to increase aerobic activity was inconclusive so far, requiring additional laboratory experiments.

Results from the efforts at the University of Karlsruhe when combined with those in the U.S. are persuasive that soil bioventing provides enhanced *in situ* bioremediation of hydrocarbon contaminated subsoils which is very cost-effective, because it does not require moving and transporting soil.

ORDNANCE DEMILITARIZATION AND MILITARY SITE RESTORATION

Cooperation between the U.S. and the Federal Republic of Germany (FRG) concerning environmental technology has recently been approved by the three services. Its nature is to provide data exchange involving detrimental effects of defense material on the environment. Data to be exchanged may include final or interim reports, including investigative protocols, analytical and statistical procedures, and sampling techniques. Five working groups have been formed: I. Hazardous Materials and Air Pollution; II. Soil and Ground Pollution; III. Water and Surface Ground; IV. Solid Wastes, Explosives, Ammunition Disposal, and Debris; and V. Noise. Several joint meetings have been held. The next meeting was scheduled for 31 August to 2 September 1992 at the German Office of Defense Technology and Procurement in Koblenz.

In the FRG, especially since reunification, munitions disposal has been a high priority subject. A number of organizations in the FRG are currently involved in various aspects of ordnance demilitarization. These organizations are very experienced in ordnance manufacture of all kinds and in research to develop more effective explosives and propellants for military application. Due to the recent rapid decline in military threat, there has been a corresponding decline in the need for such services and these organizations are applying their expertise in various aspects of demilitarization.

The Disposal Facility Corporation (EBV) Vogelgesang, FRG was recently formed to provide environmentally acceptable disposal of excess munitions. It is part of an undertaking by the Diehl Conglomerate, a munitions and military rockets manufacturer.

Discussions were held with Dipl.-Ing. Franz Gross, an Assistant Manager for EBV, and Dipl.-Ing. Rainer E. Schuricht, Project Manager, representing Ammunition Delab. (Disassembly) Engineering & Services (ADES), also part of the Diehl Conglomerate. Mr. Schuricht is a munitions expert and was a Lieutenant Colonel in the army of the former German Democratic Republic (GDR). He was in Iraq recently as a member of the United Nations Weapons Inspection Team.

One consequence of German reunification was huge amounts of excessive and obsolete munitions, remaining after demobilization of the 150,000 man former GDR Army. Initially, there were 350,000 tons of these munitions; 200,000 tons were sold to other countries, leaving 150,000 tons. To this is added an unknown quantity of NATO excess munitions the Germans must dispose. The former Soviet Union has deposits in the GDR (former Eastern Germany) of approximately 1,000,000 tons of

munitions. The Russian Army thus far says they will take these munitions with them when they leave the FRG, which has been agreed to occur in 1994. However, since this material must cross Poland, that country intends to charge 400 to 700 DM per axle of transportation vehicle. As a result, Russia is exploring the feasibility of ocean transport across the Baltic Sea. When the Russians leave in 1994, any munitions remaining behind must be demilitarized by the FRG. The quality and shelf life of the material is questionable and the world market for munitions saturated. The EBV facility at Vogelgesang has been converted from an inspection, refurbishing and assembly plant into a disassembly and disposal plant, much of the equipment for safe handling of munitions remaining the same. In 1991, 18,000 tons of munitions were disassembled by a combination of skilled manual labor and semi-automatic equipment. The resulting items generated were metal shells sold as scrap; TNT which is to be sold to the mining industry, but faces a declining market; propellants and fuses which must be destroyed; and electronic devices like sensors and gyros. This work must be done with stringent worker safety in mind, and with increasingly stringent environmental controls. The TNT can be melted out of the disarmed shells, because its melting point (80°C) is well below its ignition point, but this is not the case for other explosives. For this a high pressure water jet will be used to slice the disarmed shell into several pieces prior to incineration. This incinerator will be able to destroy a variety of materials and will include a combustion chamber capable of withstanding an explosion. It will be capable of incinerating large quantities of contaminated wooden ammunition boxes, and it will provide stack gas scrubbing to meet the very stringent German emission law, in accordance with its 17th revision. The plant will be able to provide 70 percent of its electric power requirements from the incineration of the explosives and wood ammunition boxes. Disposal of large quantities of wooden ammunition boxes is a problem in the U.S., because the wood is heavily impregnated with toxic pentachlorophenol, which prevents rotting for long periods. At the time of this visit in March 1992, the plant was able to disarm and disassemble munitions of all caliber, remove the TNT by melting, and destroy waste propellants by open burning. These activities were in progress, and were demonstrated. Open burning of propellants is temporarily permitted while procurement of the incineration equipment is underway. The facility is obviously not in full operation.

At Pinnow [in the eastern (new) states of the FRG] there was an ordnance manufacturing facility that produced wire-guided anti-tank rockets for the Army before unification in 1989. This facility was transferred to Buck Enterprises, a long-established multi-faceted business organization, by the German government with the agreement that jobs will be created in the new states. Buck Enterprises is presently conducting a disassembly operation for 3 million unsafe signal flares, recovering powdered aluminum, and destroying the remaining material in an operational hazardous waste incinerator. There is diversified activity at the plant in Pinnow, in an attempt to generate jobs and the recognition that they will soon be finished with the signal flares and similar military material. This diversified activity involves production of hospital equipment, particularly beds for the elderly, prefabricated housing units, such as have been constructed in Russia for the former Soviet soldiers. The facility at Pinnow is currently under-utilized.

The Nuclear, Biological, Chemical (NBC) Defense Research and Development Center of the Federal Armed Forces is located at Munster. This Center produced and tested chemical warfare agents as early as 1916, occupied 16,000 acres, employed 6,000 people working in three factories. Considerable amounts of chemical agents and munitions remained after the end of the First World War. It was intended to remove this material by train in order to load it on ships, from where it was to be dumped into the Baltic Sea, which would be unthinkable today. However, a freight train fully loaded with chemical munitions, ready to leave, exploded on 24 October 1919. One thousand tons of

TNT, 230,000 mines, and one million shells of different caliber were part of that explosion. Bursting chemical munitions devastated the installations and contaminated the surroundings. There was essentially no cleanup of the contaminated area. Prior to World War II, the area was increased to 24,700 acres and used by the German Armed Forces as a chemical weapons testing ground. Extensive production plants and testing facilities were built again, including the production and testing of nerve agents. After World War II, the installations were handed over to the British Occupation Forces who operated the production lines for approximately 24 months to learn the procedures. Then, the technical facilities were dismantled and most of the buildings blown up. No records were kept of activities after 1945. What remained was the so-called "Red Area," where chemical munitions from World War I and II are still being found today, and decontamination continues to be a problem. This is off limits to any training activity. The "Yellow Area" may be driven through, but no digging is permitted.

The final destruction of chemical agents still remaining from those days is being carried out at present by an operational incineration facility especially designed and constructed for that purpose. A description of this incineration facility was presented by Dr. Martens. A tour of incineration plant was conducted by Mr. Grote. Figure 2 is a description and schematic of the incineration plant. An installation to decontaminate 0.5 to 2.5 tons of soil per hour by plasma arc technology is planned.

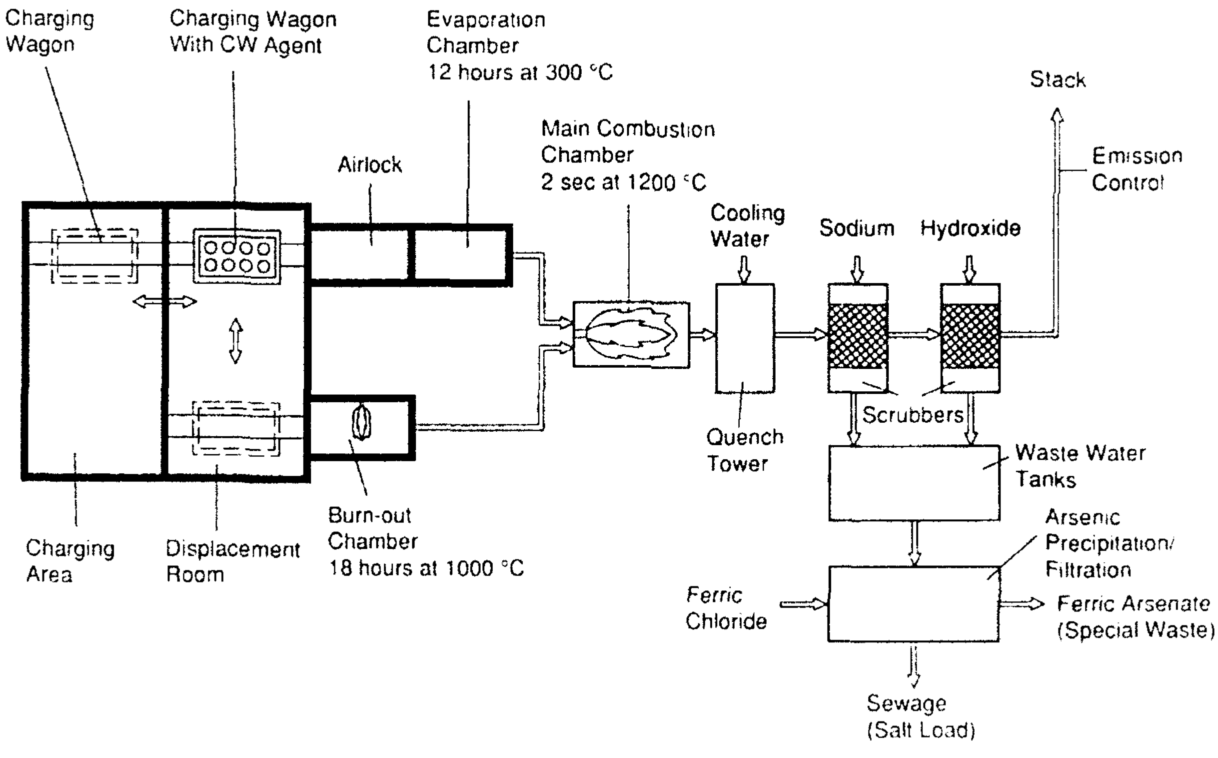

Figure 2. Functional Diagram of Incineration Plant.

A plasma arc temperature of 20,000°C will result in a slag temperature of 1600°C and over 1200°C in the oxidation chamber. The system is expected to be fully operational in 1996. The U.S. Army is currently proceeding with a full-scale demonstration of detoxifying explosives-contaminated soil by a microbiological method, called composting. The U.S. Navy (NSWC, Indian Head) has recently published an announcement in the Commerce Business Daily, seeking proposals for microbiological solutions to treat soil contaminated with TNT and other explosive materials. These biological approaches are being pursued, in part, because incineration is more expensive and involves a tedious and often politically sensitive permitting procedure. Nevertheless, incineration is fully effective, and the plant planned at Munster may provide valuable prototype information, in terms of design, construction, performance testing, and full scale certification. In 1958, the Federal Armed Forces Test Center for NBC Defense was established on the same site at Munster. This agency is headed by the Director, Professor Dr. Helmut Krueger and has a budget of 47M DM/year. The professional staff numbers 370, including 47 scientists, 73 engineers, and 100 technicians. The scientific and technical activities of the Center are:

- Improving the protection of the armed forces against nuclear, chemical, and biological threats
- Performing theoretical and experimental studies to obtain fundamental scientific data for NBC protection
- Incorporating international experience and findings in the field of NBC protection into the development of military material and experimental studies
- Elaborating the scientific and technical fundamentals for hardening of military material and weapon systems against the effects of nuclear and chemical weapons, and
- Solving environmental problems involving radiological, biological, chemical, and toxicological problems.

An experimental system for detoxifying tritium wastes was described by Mr. Wolf. These wastes are primarily used fluorescent instrument dials which represent a radioactive disposal problem. The fluorescent material is combusted in a gas stream and the tritium gas (THO and TDO) is collected over an absorbent material which concentrates the radioactive material, resulting in a significantly reduced volume. The process appears to be simple and straightforward. A patent application has been filed. Operations at Munster involving locating, identifying, disarming, and disposing of unexploded munitions are a part of the military training operations and are under the command of Colonel Wunderlich. Between 1956 and 1960, 40,000 pieces of munitions were found; from 1960 to 1977, 11,500 items were found without serious searching; from 1977 to the present, 8100 items were discovered. Some areas are contaminated with mustard gas, other areas have been closed due to unknown levels of arsenic contamination. There has been great concern about arsenic dust, particularly during wind storms when the ground is dry. These heavily contaminated areas continue to be a source of concern, but a thorough or complete remediation would be too expensive. There are warehouses full of munitions from both world wars, which are slowly and steadily being disarmed under remote controlled conditions to minimize personnel danger. Part of the problem at this stage is the difficulty in locating buried ordnance. The device currently in use is based on a ferromagnetic principle, scans the ground at a 60° angle, but cannot distinguish between small buried fragments from exploded shells and unexploded ordnance. Therefore, the search rate is very slow. The mobile side-scanning radar developed at the Naval Research Laboratory may be useful here if it can distinguish between an unexploded buried shell and shell fragments from previous explosions.

The Messerschmitt-Boelkow-Blohm G.m.b.H. [Corporation (MBB)] at Schrobenhausen (near Munich), FRG, is a division of the Daimler-Benz-Konzern conglomerate. The MBB is another

corporation active in ordnance disposal. The Schrobenhausen plant is large (22,500 m^2) and well equipped for development, production, and disposal of munitions. There are 700 employees, possession of about 700 patents is declared, and an annual business turnover of DM 200M. The MBB is prepared to dispose munitions at low cost, recycling as many materials as possible, while complying with environmental regulations. The MBB corporation is interested in overall site restoration projects. They maintain that there are 50,000 toxic waste impacted sites in the FRG, 10 percent of which are in urgent need of remediation; estimates the cost of remediation for the next ten years for the most serious sites to be 17-25 billion DM; that there is long-term restoration work for the next 50 years; and as far as the new states (former GDR) are concerned, that represents a "bottomless pit" of contaminated drinking water, rivers, air, and soil.

An example is given of the municipality of Stadtallendorf, located 20 km east of Marburg, in the former (Western) FRG. This area produced TNT from 1941 to 1945. There are 26 toxic materials in the ground, including neurotoxins, and 17 toxic materials in the water. The MBB corporation recommends the ground be decontaminated at 60,000 tons per year and a cost of 150 million DM. Since the emphasis is remediation through incineration, which involves moving soil, the process is both labor- and capital-intensive. *In situ* bioremediation of what are primarily organic nitro compounds would reduce the cost dramatically. The U.S. Army's experience in composting may be applicable.

With respect to ordnance disposal, MBB proposes the following approach:

- Recycling of the explosives
- Incineration of the explosives without disassembly if the munitions is less than 25 mm caliber
- Incineration of the explosives after disassembly
- Reuse of as many materials as possible.

MBB is prepared to equip the FRG with mobile or permanently located munitions disposal plants, including sorting, storing, disassembly, destruction at low cost, all within environmental requirements. The primary method of destruction is incineration. This requires compliance with stringent air quality standards. The scrap of cutup munitions enters an oil-fired revolving retort (rotary kiln), followed by an afterburner, a waste-heat boiler, spray dryer, hot gas filtration, three-phase washer, coke filter, a NO_x removal facility, followed by the exhaust stack.

In recognition of the relatively high cost of state-of-the-art incineration, MBB proposes research for alternative means of disposal. One approach involves microbiology in which an aqueous suspension of the explosive waste is combined with molasses under anaerobic conditions, followed by an aerobic step, which results in mineralized decomposition products. Another approach consists of continuous hydrogenation of explosives. In this process the material is dissolved in an appropriate solvent at elevated temperature. The solution is pumped through a filter catalyst in the presence of hydrogen gas, and the dissolved hydrogenated reaction products are separated from solution.

Another organization involved in ordnance demilitarization is the Fraunhofer Institute for Chemical Technology, located in Pfinztal (Berghausen), FRG. This Fraunhofer Institute has been supported in part by the German government for conducting military research into propellants and explosives. The institute is responding to a decline in this support by seeking work in environmental technology. Their current research effort is in the solvolysis of propellant and explosive materials. Plastic-bonded

(polymeric) high energy materials are widely used in the manufacture of ordnance, because the polymeric materials such as polyurethane provide excellent stability which is important in handling. The solvolytic process being investigated is effective in hydrolysing and therefore breaking the polymeric binders, freeing thereby the crystalline explosive materials for recovery and potential reuse as well as demilitarizing the ordnance. This chemical process is conducted in aqueous medium at elevated pressure and temperature up to 230°C. Propellants based on nitrocellulose are readily hydrolysed at 170°C in a sightly alkaline solution, after which the resulting material is readily biodegraded.

Discussion and Analysis

Until relatively recently, disposal of unwanted ordnance was achieved routinely by open pit burning and detonation; a refinement in the U.S. was to apply numerical modeling, combined with wind velocity and direction, and restrict open pit disposal to when the model predicted optimum atmospheric dispersion over sparsely populated areas. This, too, is no longer feasible due to atmospheric pollution. There was apparently little interest in recovery and reuse of propellants and explosives during the availability of open pit disposal. Currently, it has become important to recycle materials to reduce environmental impact and because it is perceived to be economical. Whether the reuse of explosives and propellants for military ordnance is economical still needs to be determined. Aside from the apparent glut in ordnance worldwide, the question of reliability of the reusable material will have to be settled. It is unlikely that the public would be willing to accept recycled lubricating oil for their automobiles. A similar problem may exist in military acceptability of recycled propellants and explosives. The DoD is faced with an annual disposal of approximately 280,000 rounds of munitions of all caliber. Recycling must be evaluated in terms of the energy costs involved. The planned use of adequately equipped incinerators in the FRG suggests minimal interest in recycling of ordnance materials. The German position is that their primary job is to get rid of the obsolete munitions. This is to be accomplished in less than five years. It is confidently assumed that the Russians will take their munitions with them when they leave in 1994. In view of this, it is not likely that there will be much government sponsored research for demilitarization methods other than those already in place using incineration. Thus, it appears that there are more organizations eager to perform demilitarization than there is work for them, especially since the German government wants the work done in the east (new states) which is economically depressed. Concerning the need for extensive land remediation that MBB recommends, this will depend on the priorities assigned by the German government which is still deeply involved in the rehabilitation of the new states. There is potential application for emerging technology if it provides credible promise for demilitarization by a less costly method than incineration. Examples described are biodegradation, chemical solvolysis, and catalytic hydrogenation. Another possibility, being studied by the U.S. Army and Navy is energy recovery.

A Broad Agency Announcement (BAA 92-01) in the Commerce Business Daily by the Indian Head Division of the Naval Surface Warfare Center asked for Fundamental Research and Applied Technologies in the Ordnance Environmental Area. The stated goals of the program are to develop widely adaptable technologies that will minimize the impact of ordnance related hazardous waste on the environment and to develop alternatives to the open burning/open detonation process of eliminating such hazardous waste. Proposals were asked to address one or more of the following categories:

1. Manufacturing of ordnance and ordnance components and Chemicals

2. Maintenance of ordnance items
3. Testing/training by item substitution/simulation
4. Use of more environmentally benign materials in ordnance design or processing
5. Ordnance contaminated site restoration
6. Ordnance storage technology
7. Disposal/destruction of explosive ordnance
8. Recycling of ordnance and ordnance components.

This BAA covers all of the ordnance issues discussed so far, and clearly illustrates a Navy need for ordnance-related environmental technology. A total of 52 responses was received, applying to categories 1., 3., 5., 7., and 8., including one proposal from the FRG.

The forthcoming meeting of the Data Exchange Agreement groups between the FRG and the U.S., particularly Group IV on Solid Wastes, Explosives, Ammunition Disposal, and Debris will address these issues.

SOLID WASTE MANAGEMENT AND RECYCLING

Solid waste is considered as a secondary raw material at the Institute for Separation, Purification, and Waste Management of the Technical University at Aachen. The Institute's background and experience is in mining engineering which involves handling, separating, concentrating, and enriching various portions of minerals. They have adapted their experience and equipment to deal with the large and growing problem of domestic and industrial waste management. This involves developing methods and equipment for separating synthetic materials wastes, metal, glass, paper, and others to achieve solid wastes of greater quality that are then available for the highest recycling application, and therefore, for the greatest financial return. In many cases this can make the difference between successful and unsuccessful recycling. The Institute is very busy with a variety of contractual assignments from industry and municipalities. Contacts at the Institute are Dr.-Ing. Heinz Hoberg and Dipl.-Ing. Stephan Buntenbach.

They have developed and are evaluating a number of processes which are divided into three general categories. Examples in each category follow:

1. Separation of Domestic Solid Waste and Treatment of Industrial Waste Products
   - Method of separation of waste glass shards by a combination of an optic-mechanical technique, involving color distinction by wave length difference
   - Sorting and separation of synthetic plastics
   - Treatment of food wastes (garbage) by rapid, anaerobic composting
   - Market study and establishment of a separation concept for synthetic plastic waste in the Ruhr region
   - Investigation of the use of synthetic plastic mixtures as a source of energy for cement production
   - Investigation for the treatment of wastewaters from the glass bottle industry (bottle reuse)
   - Identification of flotation agents for flyash separation
   - Development of a separation process for different metals through the application of magnetic field-induced eddy currents

- Investigation on the separation of chlorofluorocarbon residues from polyurethane insulation in discarded refrigerators

2. Development Plans for Various Municipalities Legally Required to Dispose of their Solid Wastes
   - Establishment of a solid waste management concept for the Euskirchen region
   - Establishment of a management concept for special wastes in the Industrial Saar region
   - Investigation to improve the safety standards for domestic solid waste dumps through measures to distinguish between hazardous materials from domestic wastes and industrial wastes

3. Decontamination of Contaminated Soils and Solids by Mechanical Separation Techniques
   - Investigation of the feasibility to detoxify arsenic contamination through a chemical-physical treatment involving extraction or immobilization
   - Basic investigation for the treatment of contaminated soils by means of mining ore separation techniques
   - Investigation for the treatment of harbor sediment contaminated with heavy metals.

Management of solid wastes is a growing problem. This applies equally to ships and shore facilities. The established procedure of having a contractor simply haul it away will not do anymore. Our ships sometimes have to pay outrageous prices in foreign ports to have their solid wastes taken away. The new techniques of solid waste management being developed at Aachen could be very cost-effective when applied to analogous Navy operations after off-loading. However, if a ship's force can be motivated to do some on-board manual separation of polyethylene and polypropylene, for example, the increased value of this waste could add to the ship's recreation fund. The Navy has a large, maturing ongoing R&D effort directed toward environmentally-sound shipboard solid waste management, in response to the requirement shown in Appendix A, Pillar 3, Pollution Prevention.

Of special interest in the efforts at Aachen is the third item in Category 3, harbor sediment treatment. The Navy faces a very costly disposal problem when it is time to dredge a harbor. The dredged material, since it has been a sink for heavy metals and toxic organics, cannot be ocean dumped unless it passes a rigorous bioassay test. Hazardous land fill disposal follows, but this is expensive, and increasingly difficult as available sites fill up. An ONT-sponsored effort in sediment remediation is planned for FY 93.

Recycling has become a popular term. In fact, it has become a German word without any changes. Basically, it means to use again something that has been discarded; that is, to give it value anew. This is nothing new as far as heat energy is concerned as there is extensive heat transfer (recycling) technology. When it comes to man-made materials such as synthetic plastics, it is something new. Because plastics are so inexpensive, it has been cheaper to throw them away. This is now changing and recycling has become popular. However, it is not always economical, and the recycling of specific materials has to be examined very carefully in terms of "hidden energy."

This is being investigated at the Institute for Energy Technology and Power Plant Engineering of the Technical University of Munich. Dr.-Ing. Helmut Schaefer heads the Institute. A recent investigation at the Institute is "The Hidden Energy of Beverage Cans" by Dipl.-Ing. Wolfgang Mauch, published in the Abfallwirtschafts (Waste Management) Journal, No 1/2 1990. According to

this paper, "The hidden energy of goods is the total energy requirement for their production. This includes the extraction and processing of raw materials, manufacture of semi-finished products and the actual energy used in the conversion of the semi-finished to the finished article. Also taken into account is the energy associated with the use of the article and that required for its disposal, re-use or recycling."

To determine the hidden energy requires a very detailed investigation and measurement of energy at every step of the process. This was done for three different two-piece beer cans: 1) tin plate can with aluminum end, 2) tin plate can with tin plate end, and 3) aluminum can with aluminum end. This very detailed analysis comes to a meaningful focus when we look at the results of energy comparison of aluminum and tin plate cans at various recycling rates. This is shown in Figure 3 taken from the paper by Dipl.-Ing. Wolfgang Mauch.

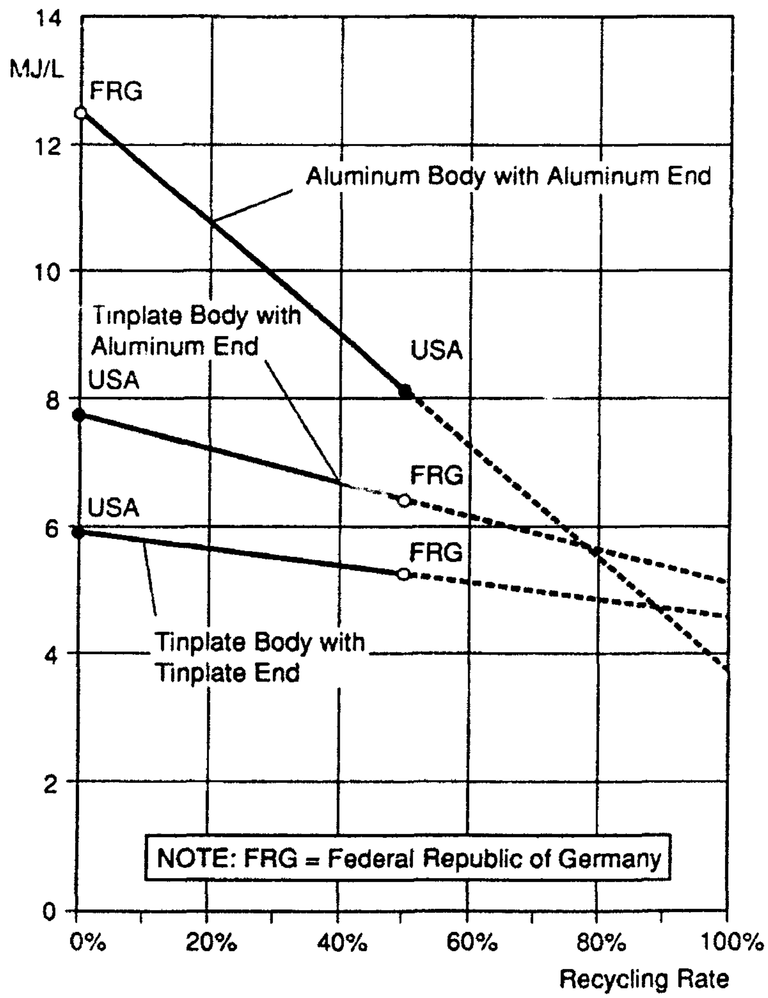

Figure 3. Hidden Energy Consumption in Can Production for 1 Liter Beer Cans.

"Without recycling, the hidden energy requirement of the aluminum can is more than twice that of the pure tinplate can. At a recycling rate of 50 percent, the requirement is only 55 percent above that for the tinplate can. Only at a recycling rate of 89 percent is the energy requirement for both products on a par at 4.8MJ/L. When the aluminum can is compared with the tinplate can with an aluminum end, equivalence occurs at a recycling rate of 78 percent and 5.7MJ/L."

Changes in the recycling process can affect the slope of the lines shown in Figure 3. For example, energy is consumed in removing the paint from the used cans prior to melting, because the paint is removed by an oven roasting process, which also causes a 15 percent loss of aluminum. When the paint can be removed by an enzymatic stripping process such as the one being developed under ONT sponsorship, the impact could be noticeable. The hidden energy study for recycling beer cans is instructive.

The FRG is the first nation to require business and industry to collect and recycle cans, bottles, cardboard, paper, and plastic used to package their products. Although there was considerable resistance from corporations at first, the German government was insistent. As a result, 600 companies formed Duales System Deutschland, a private company that works with local government to collect everything that can be recycled and pass it on to the recyclers. German citizens are cooperating by tossing into the provided yellow bins everything that can be recycled. Table 1 shows the minimum requirements for collecting and sorting packaging materials in the FRG, as percent of weight. Table 1 and Figure 3 show that in the FRG recycling of aluminum will have an energy penalty until 1995.

Table 1. Collecting and Sorting for Recycling

	COLLECTING	SORTING	
By:	1 Jan. 1993	1 Jan. 1993	1 July 1995
Aluminum	30%	60%	90%
Cardboard	30	60	80
Glass	60	70	90
Paper	30	60	80
Plastics	30	65	90
Tinplate	40	65	90
Composite Materials	20	30	80

Solid waste handling and recycling technology being developed at the Technical University at Aachen is playing a significant part in the success of the difficult municipal waste management plans initiated by the German government. This effort is being watched by other industrial countries to see if the German effort will serve as a model.

MARINE BIOFOULING CONTROL

Fouling organisms which attach to Navy hulls reduce maximum speed as much as 10 knots, increase propulsive fuel consumption 20 percent, decrease cruising range, and increase underway refueling frequency. The Navy pays an annual penalty in fuel costs of $75 - $100 million due to marine fouling. Current antifouling paint technology uses controlled release toxicants which are chemically incorporated in the paint. The most effective antifoulants commercially available are based on a dual

biocide of tributyltin (TBT) and copper. Release of the toxicant during dense berthing of ships in poorly mixed harbors, and during paint application and removal in drydocks, can impact non-target marine organisms and is of environmental concern in a number of countries.

The environmental price of the use of this very effective but also toxic biocide remains a controversial issue. Extensive field research conducted by the U.S. Navy has demonstrated that very effective, but expensive, state-of-the-art means exist in controlling drydock emissions. Nevertheless, scientifically unfounded low state BT water quality standards, as well as worst-case orientations and media attention, have made TBT paint removal and application prohibitively expensive for the U.S. Navy. This is not the case for world commercial shipping which obtains affordable drydock service in parts of the world much less affected by worst-case environmental management.

Use of these paints has been banned in the U.S. and several other countries only for marine craft under 25 meters in length, which primarily affects recreational boats. This is appropriate as these vessels are densely berthed in sheltered harbors and can manage adequately with less effective antifouling paints.

Nevertheless, current technology antifouling paints provide substantial economic benefits from fuel cost avoidance. The International Maritime Organization calculated in 1990 that fuel cost savings by world commercial shipping, 90 percent of which use the most effective organotin antifouling paints, is $2.5 billion, primarily through reductions in distillate fuel consumption of 7.2 million tons annually. This corresponds to 60 percent of the oil production from the North Sea. In ecological terms use of TBT antifouling paints offers significant savings in the use of fossil fuels and the reduction in emissions of carbon dioxide (23 million tons per year) and sulfur dioxide (58,000 tons per year).

In recognition of the very substantial economic benefits to world shipping, the European Community under its MEDSPA program has financed a demonstration project to develop treatment of organotin contaminants by biological means. An international team of scientists and consultants has been established. This team is led by Dr. David Abel and Dr. Tony Abbott of the Ecology Centre of the Sunderland (U.K.) Polytechnic Institute. Participants in this program are the New University of Lisbon (Portugal); the Euro-Mediterranean Centre on Marine Contamination Hazards (Malta); the University of Malta; Courtaulds Coating plc (U.K.); Organotin Environmental Research Program (ORTEP), and the Association of West European Shipbuilders (AWES). The aim of this effort is ambitious and extensive and is described in more detail in Appendix B. Since the U.S. Navy has conducted extensive research in this area, (much of which has been published), interaction with the MEDSPA program has been initiated through the efforts of ONR Europe. Exchange visits are planned to discuss details and to avoid as much as possible repetition of efforts already successfully completed.

A paper entitled "The Marine Biocide Tributyltin: Assessing and Managing the Environmental Risks" was published in *Environmental Science and Technology* in February 1992. This paper states:

> ***"Subsequent to the regulations, bioassays revealed that Virginia's concerns over TBT effects on oysters and crabs were unfounded. Studies determined the C. virginica (the U.S. commercial oyster) was far less sensitive to TBT than C. gigas (the U.K. and French commercial oyster) and did not have the shell-thickening response that C. gigas demonstrated at low TBT concentrations. Additionally, it was found that the blue crab (found throughout the Chesapeake Bay) is capable of***

effectively metabolizing TBT at exposure levels it would likely receive in the environment."

It was the Virginia regulations, requiring a TBT water quality standard of 1 nanogram/liter (1 part per trillion), one order of magnitude lower than the U.S. EPA requirement, which was primarily responsible for stopping the implementation of these effective antifouling paints for U.S. Navy ships. Continued use of these antifouling paints by world shipping, and by recreational craft in those countries where their use is not banned, continues to raise environmental concerns. It is hoped the E.C. MEDSPA project will resolve these concerns and establish a balance between reduced hydrocarbon fuel consumption and generation of global warming gases, and effects on marine organisms. Ongoing research by the Navy is directed to the development of non-toxic antifouling paints. These include natural antifoulants and low surface energy coatings. The most promising are the latter. These materials, being non-toxic, will permit attachment of sessile organisms; however, the attached organisms can easily be removed. This effort has been funded by ONR, ONT, and beginning in FY 93 support by OAT is anticipated.

In the meantime, the U.S. Navy is using commercially available toxic copper ablative paints which are less effective than the organotin paints, but which have caused less environmental concern so far. Because these paints are less effective, 25 percent of the 170 ships painted so far have exhibited unacceptable hull fouling prior to the required 5-7 year service life. This requires commercial underwater hull cleaning which releases excessive amounts of toxic copper to the environment in a short time period. It is anticipated that such toxic releases will be considered environmentally unacceptable by the regulatory agencies responsible for those bodies of water. In response to this problem, Navy research is underway to develop an automated, tethered underwater "smart" vehicle that will identify hard fouling organisms where they occur and remove them without disturbing the paint film, releasing thereby only negligible amounts of copper. This effort is currently funded by ONT with transition to OAT proposed.

Another environmentally friendly solution is proposed by Professor Uriel Safriel of the Hebrew University in Jerusalem. Limpets, Patella caerulea, are snails with pyramidal shells very common to nearly all rocky shores worldwide. Adult limpets feed on the sprouting spores of algae and crush the very young barnacles and young stages of other sessile invertebrates. They are able to do this with a rough rasping tongue that moves along the surface and literally bulldozes away any settled organisms. However, in nature, barnacles possess much faster growing rates than limpet snails who cannot compete effectively for space during the short time available for community establishment. Once a barnacle has reached a certain size, the limpet will no longer be able to remove it. What is proposed by Dr. Safriel and his colleague Professor Yosef Cohen of the University of Minnesota is the introduction of adult limpets on a freshly cleaned surface, giving them an artificially provided competitive edge.

Initial experiments on test panels have demonstrated that after 40 days of submergence in the commercial port of Ashdod, the control panel is densely populated by barnacles and other fouling organisms, while the experimental panel is free of sessile organisms and is inhabited just by the transplanted adult limpets. This is shown in Figure 4. Since the limpets are mobile, and therefore, not permanently attached to the surface, they fall off when the surface is in motion.

Research efforts are directed to establishing the "return time" (t_r) which is the time required for a foraging limpet to return to a previously foraged area; and the "critical time" (t_c) which is the

minimum time it takes a fouling organism to settle and get established on the surface such that it cannot be removed by a foraging limpet. The preferred density and size distribution of limpets will be the one that achieves the t_r/t_c for the whole surface $>=1$. Additional optimization research involves selecting and raising those strains of limpets which most effectively achieve that ratio.

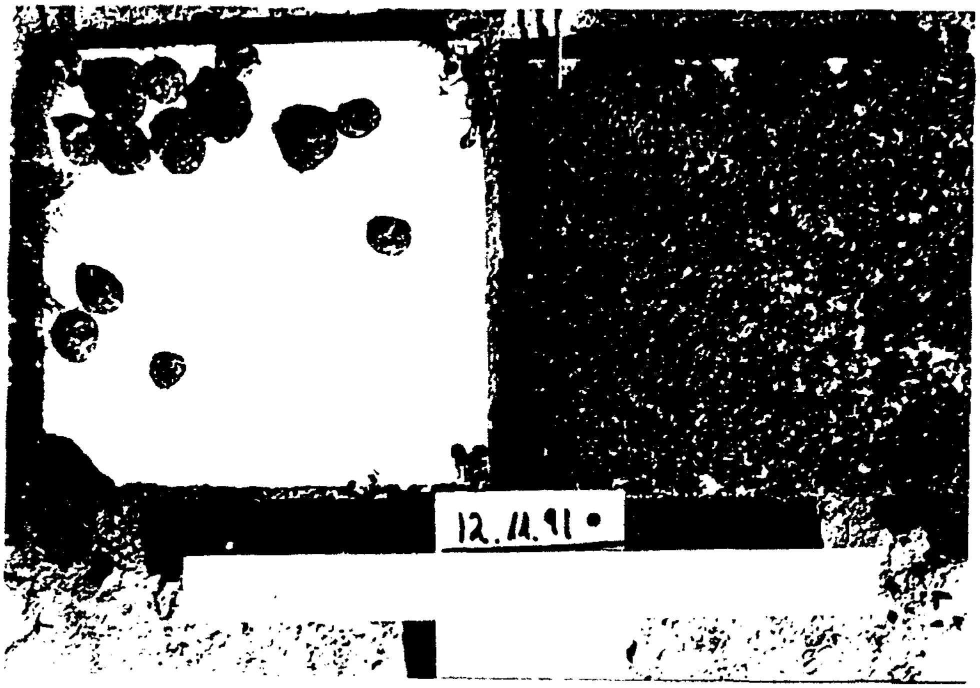

Figure 4. Mobile, transplanted adult limpets (left) keep the panel clear of barnacles which cover the control panel (right).

Whether this environmentally benign concept can be converted to practice for Navy application remains to be seen. Limpets would have to be manually applied by divers on a freshly painted or cleaned hull in a harbor. Although a ship may be in port for months before being deployed, it usually makes frequent short trips to maintain operational readiness. Limpets would have to be reapplied upon return to the pier. If the hull is painted with a toxic paint, the limpets will be affected because they will graze on the organisms that accumulate the toxicant. If the hull contains a non-toxic low surface energy paint, the limpets will not be needed if the paint performs fully as conceived; if it does not, the limpets could provide a valuable degree of optimization. Limpets would have to be raised and maintained near the pier for ready application by divers.

At present, this approach does not appear practical for Navy hulls, especially since most recreational craft and all ocean going vessels will continue to use toxic antifouling paints for this decade and perhaps longer. As stated earlier, for the forthcoming low surface energy non-toxic paints, if they do not perform fully as conceived, limpets might provide a degree of optimization. When translated into fuel cost avoidance, this uncommon low-tech method of antifouling may justify maintaining living organisms for application to the hull.

Limpet biofouling control for permanent underwater structures appears more *promising*. Wooden piers which are in wide use are rapidly damaged by marine wood borers. Creosote is used to protect the wood. Creosote releases toxic polynuclear aromatic hydrocarbons into the water, including the carcinogen anthracene. Limpet foraging would have to consume wood borer juveniles. Permanent structures that are made of steel, such as oil drilling platforms, are seriously affected by cumulative marine fouling and must be regularly cleaned by divers to prevent compromising structural performance. The U.K. Department of Energy is funding the University of Strathclyde in Glasgow to develop ultrasonic tools utilized by divers to remove accumulated marine fouling from such underwater structures. Regular application of limpets could significantly reduce the frequency of such maintenance. Ultrasonic cleaning technology for fouled stationary structures is also applicable to the previously mentioned effort to develop an automated underwater vehicle for "smart," environmentally-friendly fouling removal. A contractual agreement between the U.S. Navy and the University of Strathclyde to provide such technology is in place. This arrangement was facilitated by ONR Europe.

The limpet research at the Hebrew University in Jerusalem should be watched for developments that would help determine its practical application to provide fuel and underwater maintenance cost avoidance by a clearly low technology approach.

POLLUTION PREVENTION

Preventing or significantly reducing pollution at the source has become axiomatic in principle, but difficult in practice. Treatment at the end of the pipe has the advantage of not interfering with the industrial process that is the source of the pollution. But treatment at the end of the discharge pipe suffers from the technical and therefore economic difficulties of removing pollutants from a dilute solution or suspension. While dilution can be large, it is not low enough in most cases to meet increasingly stringent discharge regulations. Reducing pollution at the source can be accomplished by treatment at the site with, for example, fluidized bed bioreactors; however, pollution prevention at the source ultimately requires modifying the manufacturing process. Two industrial processes where this applies are electroplating and paint application. Both processes serve to protect surfaces from corrosion and erosion and therefore contribute to the performance, maintenance, and the life cycle of expensive equipment and indirectly to the safety of personnel manning such equipment. Both processes are in use by the U.S. Navy, Army and Air Force.

Research at the Fraunhofer Institute (FhG) for Production Technology and Automation, Stuttgart, FRG, has developed principles for significant pollution prevention from these processes. A description of these principles follows.

- ***Electroplating Design***. The part must be designed to facilitate a plating operation that enhances conservation. This requires an approach which integrates environmentally-friendly electroplating with high product quality and economy of production. The geometry of the part must permit easy drainage of the plating and rinsing solutions. When this is not possible, the location of necessary drainage holes and places of suspension of the part must be carefully considered. Other aspects of the production process impact on the ability to minimize plating waste. For example, inadequate preparation of the part caused by economizing in the machining and surface preparation steps, can require compensatory plating steps which increase the difficulty of making the process environmentally friendly.

- *Operating Flow Diagram of the Metal Plating Process.* Introduction of environmentally-friendly methods, controlling and combining complex technology requires a clear understanding of the fundamental processes involved. Relevant process parameters, including sources of impurities, must be described in the flow diagram. This must also include additive and subtractive effects. A detailed flow diagram facilitates understanding the process which then permits its configuration to provide production which is environmentally friendly, of high quality and economy. Eventually, such detailed understanding of the process permits computer simulations which can lead to optimizations with only a minimum of test trials.

- *Process Design.* A further criterion for hazardous material minimization is in the use of the plating solution components. Any excessive use of ingredients, either in type or quantity, leads to an increase in hazardous wastes. Examples are in the reduction of heavy metal concentrations in plating baths as well as replacement of toxic complexing agents, such as cyanide-free zinc baths, ammonium-free, nickel baths without applied voltage, EDTA-free copper baths without applied voltage.

- *Process Control.* Through the introduction of quality assurance steps, a definite, consistent quality is achieved, which leads to a reduction in waste. Consequently, post-treatment waste is reduced and environmental impact is minimized. In order to conduct an environmentally-friendly industrial process, it is not sufficient to maintain the plating operation within precisely defined limits. All associated steps, such as pretreatment, cleaning, must also be kept within precisely defined conditions. Use of an expert system to support quality assurance is a concept which permits intervention in the finishing step before a check at the completion of the plating process detects an error.

  Such a concept depends on the development of a knowledge-based expert system, that must be tested and optimized for trouble-shooting purposes. This requires the necessary sensors to measure the relevant parameters. Some of these sensors are commercially available, others must be developed. The highest quality assurance of the final product is attained when an automatic control system, based on an expert system, is introduced. Such a system can provide dynamic regulation as the process parameters drift from their established limits.

- *Rinse Techniques.* An important condition for reducing wastewater disposal as well as recovery of materials from the plating bath consists in optimized rinse techniques. Today it is standard procedure to use three rinses after the plating bath. In order to achieve industrial (economic) recycling, the first rinse water should attain up to 25 percent of the plating bath concentration. There are a variety of rinse techniques currently in use as shown in Figure 5. These are spray rinsing above the plating bath, stationary dip rinsing, flow rinsing and dual cascade rinsing. The final rinse should achieve the established rinse criteria. The rinse water can be recycled after being treated by ion exchange to remove the plating salts.

In many cases, the use of conventional electroplating technology, even when carefully applied, is not adequate in dealing with environmental problems. New techniques must therefore be developed for the future. Conversion from a plating process that involves a series of chambers to a process using only one reaction chamber has application in specific cases. The part being plated remains stationary in the chamber or actually becomes a part of the chamber. The plating solutions are introduced into the chamber, one after the other, in accordance with the process. In other words, instead of bringing

the part to the plating chemistry, the plating chemistry is brought to the part. This is generally known as "Single Chamber Plating," and can be used in plating cylindrical objects, in which case the object becomes a part of the reaction chamber, Figure 6.

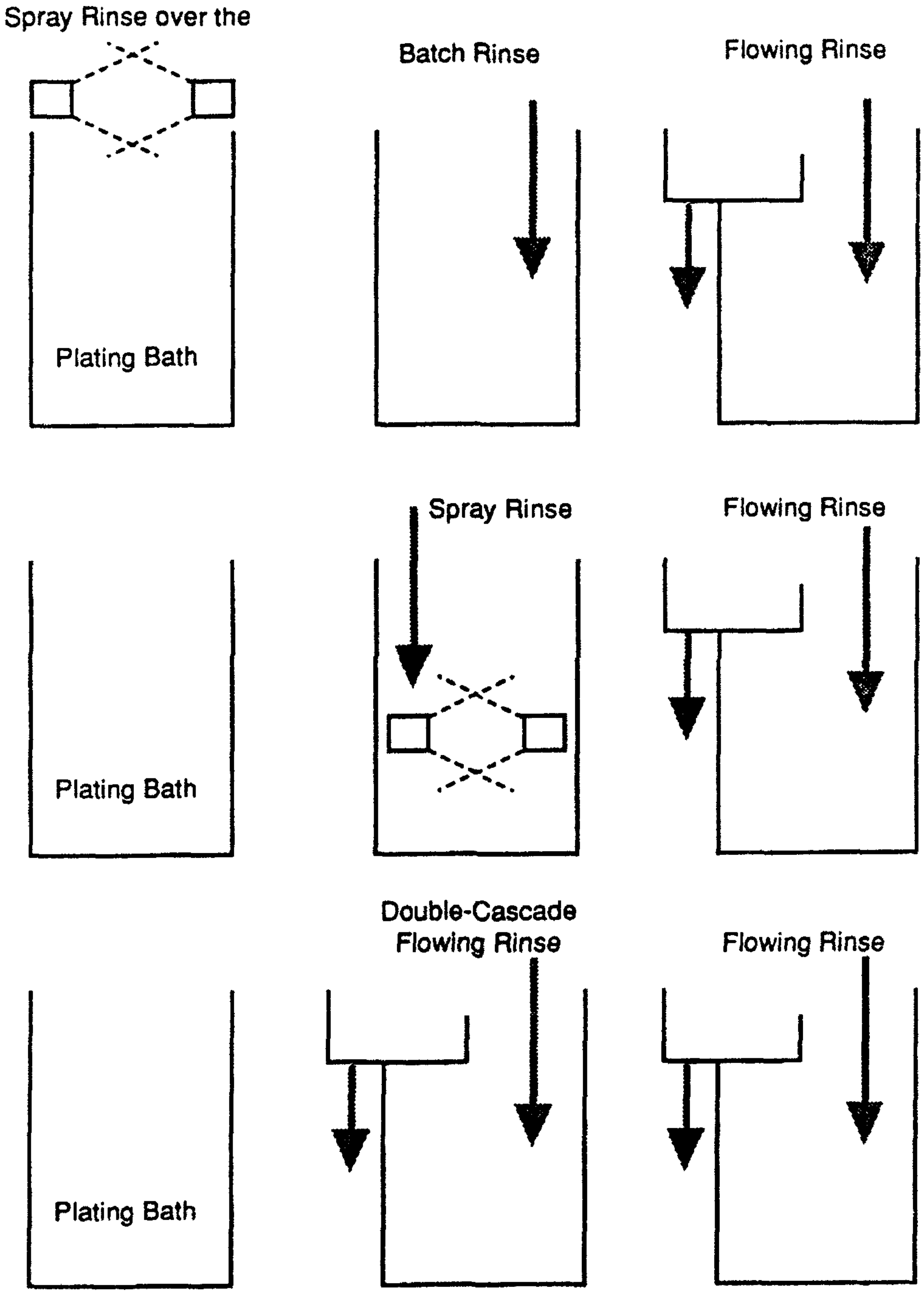

Figure 5. Water-conserving rinse technique.

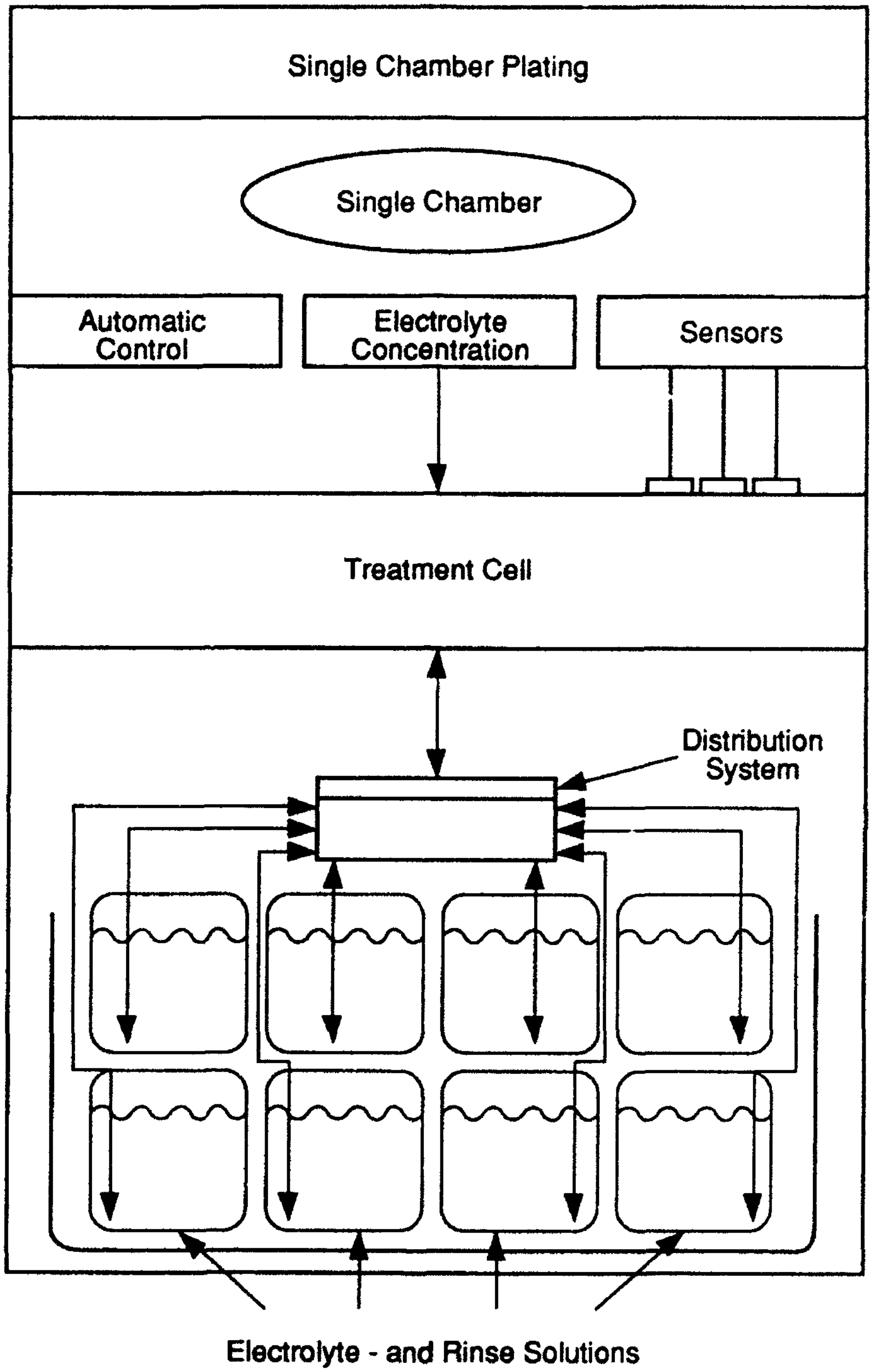

Figure 6. Schematic of New Process Concept.

Navy electroplating operations are extensive and involve parts of different shapes and sizes. Electroplating is used primarily in repair, overhaul and maintenance of ships and aircraft to bring various components of military equipment back into compliance with specifications. Compliance with military specifications has been the primary consideration. However, Navy electroplating operations face serious environmental management problems at present and in the near future. As air and water discharge requirements become increasingly stringent, Navy operations will face notices of violations, fines and threat of closure. The Fraunhofer Institute (FhG) in Stuttgart is developing environmentally-friendly electroplating technology for the manufacturing industry which involves mass production of identical pieces, as distinct from a variety of equipment parts having a fixed design. Nevertheless, the principles developed can be applied in approaching the goal of zero discharge for Navy electroplating.

Experience by the FhG in implementing such changes in the FRG were very positive, as soon as the plant manager discovered that this would help him not only in meeting environmental regulations, but would also reduce costs by saving and recycling materials. Implementing such changes at Navy electroplating operations might be more difficult for a number of reasons. First, the primary, if not the sole purpose, is to the meet military specifications. Second, cost avoidance awareness is generally subordinated to the first reason. Third, many of the parts to be plated are of different sizes and configurations, as stated. The environmental technology research community must be aware of these implementation difficulties from the start and must involve itself in the implementation process. When this does not occur, the new technology is either not implemented at all, or implementation takes far longer than necessary. Since electroplating of military parts affects all services, a tri-service effort in adapting and applying the environmentally-friendly electroplating technology being developed at the FhG seems appropriate.

Paint Spray Application

There are several causes of paint and solvent loss which contribute to toxic waste generation:

1. Overspray, when the paint droplets fail to reach the surface
2. Overly thick paint films
3. Uneven film thickness distribution
4. Color change
5. Equipment cleaning, and
6. Touchup.

There are a number of steps that can potentially be taken to minimize emissions and waste from spray paint application.

Primary Steps

Coating systems and techniques that have a low emission and waste potential can be used; examples are paints with a high solids content, water base paints, dip coating application and powder coating. Process and operational steps involve spray optimization, spray residence time control, use of electrostatic coating, reduction in film thickness, improvement in film thickness uniformity, reduction in touchup, reduction in spray pattern diameter, reduction in rinse waste from color changes, and overspray recovery.

Additional Steps

Process air treatment can be achieved by adsorption, absorption, condensation, biodegradation, and thermal degradation. Wastewater treatment can be achieved by precipitation, flocculation, sedimentation, neutralization, biodegradation, adsorption on activated carbon or molecular sieves, ultrafiltration and reverse osmosis. Modifying an industrial process so the pollutants are not generated in the first place is the most elegant approach to pollution prevention, but it is not the only one. Any activity that reduces the need for disposal or treatment away from the source can be considered pollution prevention. Examples discussed so far are recycling and on site treatment at the source such as the proposal to the EC by GBF (Braunschweig).

ATMOSPHERIC POLLUTION CONTROL

Europe has an adequate supply of brown coal for energy generation. However, the sulfur content of the coal requires removal of SO_2 from the stack gases. Removing 90 percent of the SO_2 is usually accomplished by reacting the flue gases with limestone slurry in a large absorber tower. The flue gases are then passed to the existing stack. Air is fed into the solution at the bottom of the tower which causes calcium sulfate dihydrate (gypsum) to form. The gypsum slurry is continuously removed from the tower and then centrifuged to produce a gypsum cake with a moisture content of 8 percent. The waste water contains other pollutants, particularly heavy metals such as mercury and cadmium, which are removed in a treatment plant before the water is discharged. The gypsum is usually of a good quality which is used in the manufacture of wallboard for the construction industry. Removal of NO_x is by catalytic reduction, usually preceded by reducing its formation through temperature control. Construction of flue gas treatment systems for large power plants is done by companies like John Brown Engineers and Constructors (E&C) U.K. John Brown E&C is an international engineering contractor and a member of the Trafalgar House conglomerate. They have designed and constructed many different plants throughout the world and have increasingly recognized that all such projects contain an element of environmental engineering. The company has also recognized that providing environmental engineering services is a part of maintaining a profitable relationship with their customers. In the U.K. the Environmental Protection Act introduced Integrated Pollution Control to compel industry to improve its environmental performance. As a result, many firms have realized the benefits of adopting an environmental policy to reduce emissions, to develop less harmful products and present a more environmentally friendly image to the consumer.

John Brown E&C has responded to this new growth industry by forming an environmental engineering group which offers a full range of services. The scope of these services include:

- On-site investigation
- Environmental audit and impact assessments
- Negotiation with statutory authorities
- Sampling and testing of discharges and preliminary problem definition
- Identification of options for reducing discharges and recycling
- Flowsheet development and pilot plant operation
- Selection of Best Available Technology (BAT)

BAT means state-of-the-art technology; that is, technology for which performance, reliability, and liability risks are known and understood. There are available a series of BATs for Air Pollution Control, Liquid Effluent Treatment and Solid Wastes and Contaminated Soil Treatment.

Examples of BAT projects by John Brown E&C are:

Client	Project Description
Powergen, U.K.	Flue gas desulfurization plant for power station
TMR International, FSU	oil/water separation plant to recover oil and clean up cooling water from the Volgorad Oil Refinery
Rhone Poulenc, U.S.	Aerobic treatment of high salt water using equalization, pH control and biochemical oxidation
The Upjohn Co., U.S.	Removal of 95 percent VOC's by refrigeration and incineration from 18 different processes
ICI, U.K.	Treatment of contaminated sulfuric acid using liquid phase acid concentration, incineration, and absorption
Exxon Chemical, France	Waste water facilities for polyethylene and poly-propylene plant involving oil/water separation and biological treatment
Texas Water Comm, U.S.	Incineration of contaminated soil and waste water treatment at an old disposal site
SNEA(P), France	600 tons per day sulfur recovery plant for refinery
DuPont, The Netherlands	Wet scrubbing to remove HCl and chlorine from effluents

John Brown E&C does not support environmental R&D. The concept of BAT, what is "best" is a matter of interpretation, is a necessary statutory concept; it has been extended to BATNEEC, Best Available Technology Not Entailing Excessive Cost, where "excessive" is also a matter of interpretation. Therefore, R&D for still better technology will usually be driven only by the necessity of cost avoidance and by serious global problems that override parochial positions of governments. Furthermore, promising emerging technology that has advanced beyond the pilot stage will probably not be utilized by John Brown E&C unless full scale field demonstrations have occurred which have provided economic and performance data, as well as risk and liability assessment for that technology. To achieve that condition requires full-scale demonstrations, which are usually expensive.

The concepts of BAT and BATNEEC as applied by John Brown E&C illustrate the tension between emerging technology that must transition to application. The DoD faces the same tension. Military site restoration, including bases to be closed, is conducted by contractors like John Brown E&G. These contractors will not include on their list of technology options for selection, those technologies for which performance, economic, risk, and liability information is not available. As stated earlier, the primary factor in admitting new technology to the list of options is affordability.

Emerging technology for stack gas treatment to meet atmospheric compliance requirements faces those problems. The removal of NO_x and SO_x by means of high energy electrons is now the subject of considerable research. Two places where this was encountered was at the University of

Strathclyde in Glasgow and the Nuclear Research Centre at Karlsruhe.

At the University of Strathclyde, Dr. MacGregor of the Power Division described the recent development and application of power pulse technology. This has ensured voltage rise times of a few hundred nanoseconds, resulting in the generation of primary high energy electrons. These electrons with energy in the range of 5 eV to 20 eV produce ionized species and radicals capable of initiating chemical reactions leading to the removal of NO_x and SO_2 from combustion gases. Following these primary processes, a number of reactions occur producing the decay of the primary species and the formation of active radicals which lead to the oxidation of NO_x and SO_2 to acidic forms. In the presence of injected ammonia, nitrates, and sulfates are formed as solid aerosols which can be removed from the flue gas with a state-of-the-art electrostatic precipitator or a fabric filter. The feasibility of simultaneous NO_x and SO_2 removal from combustion gas by corona electrochemical oxidation has been verified at an experimental test rig installed in the slipstream of the main gas duct of a coal burning unit. This emerging technology of NO_x and SO_2 emission control with a dry process may provide improvements over the current heavily used wet lime process which generates large quantities of gypsum, while the products of the dry process may lead to end products usable as fertilizers or soil conditioners.

With this potential application in mind, an Advanced Research Workshop on Non-Thermal Plasma Techniques for Pollution Control, was held at Cambridge University, England, 21-25 September 1992. This workshop was jointly sponsored by ONR Europe.

Some of problems of implementation of this emerging technology are as follows:

- High energy electrons constitute dangerous radiation which requires adequate shielding and beam control
- Adequate cooling must be provided, including high reliability controls
- While not as complex as a nuclear reactor, this system may approach its safety requirements.

The Cambridge workshop in September had a few papers on implementation studies and these were worth evaluating. The workshop did not address the cost of human safety requirements, presumably because it is not a subject requiring research.

SHIPBOARD ENVIRONMENTAL TECHNOLOGY FOR THE GERMAN NAVY

The German Navy Section SG III 3, of the Federal Office for Defense Technology and Procurement (BWB) in Koblenz is roughly equivalent to the Naval Sea System Command. This office is responsible for meeting overboard discharge standards. The German Navy plans to operate as if it were entirely in restricted discharge zones. The Baltic and North Seas currently are restricted, the Mediterranean Sea is expected to be so declared, as well as the Gulf of Mexico. Since the FRG is a member of NATO, there are regular, formal meetings to discuss progress and problems in meeting the International Maritime Organization's (IMO) increasingly stringent ship discharge restrictions.

With the largest number of ships and the largest R&D budget, the U.S. Navy has been the leader in shipboard environmental protection equipment development. However, the much smaller German Navy, while utilizing applicable U.S. Navy developments, is proceeding in some independent directions as it deems appropriate.

One of these is the development of a shipboard biological reactor to treat blackwater (human waste) and graywater (shower, laundry, and kitchen waste), using the well established activated sludge recycling principle. Early U.S. Navy experience with this approach on LHA (Helicopter Landing) class ships has been negative, primarily due to the sensitivity of the microorganisms to chemical shock and the lack of adequately trained personnel. The German Navy is in advanced development with the biological reactor approach and is applying current knowledge. Two approaches are being evaluated. In one case, the Aquachem Wastewater Treatment System, there are three bioreactor chambers in series receiving wastewater that has been thoroughly aerated. Grease from the galley is separated before the wastewater enters the first chamber. This is necessary to reduce the high biological oxygen demand of the grease. Aeration is achieved by two blowers, followed by a clarification section where the activated sludge is separated, and part introduced into the first chamber to maintain adequate bacterial concentration. The effluent from the clarification chamber is disinfected by solid or liquid chlorine products and discharged after a six minute contact time. While this disinfection step is necessary to meet IMO MARPOL regulations, it is not satisfactory in that it generates low molecular weight chlorinated organic compounds (haloforms) which are considered carcinogens. Alternative methods such as ozonation are difficult and not as effective. The IMO discharge standards cannot always be met, depending on load variations, but 90 percent of the limit is regularly attained. Activated carbon powder is used in the bioreactors, because this provides a very large surface area and thereby increases bacterial populations rapidly. Temperature is maintained at 49°C, pH at 7, sensors are used to maintain oxygen saturation, and sludge flocculation and color is checked regularly. Experience with this system has been accumulating since 1985.

Another bioreactor system being evaluated consists of two aerated chambers in series, but the activated sludge formed is returned only to the chamber in which it is formed. This creates two bioreactors in series, but with separate bacterial populations which have adapted to the separate food supply conditions in each chamber. Optimization efforts are underway to permit volume reduction of the system. I referred the German Navy to the Gesellschaft fur Biotechnologische Forschung (GBF) in Braunschweig. I suspect the GBF may have computer modeling capabilities for biological processes that could assist in optimizing shipboard sewage bioreactors.

In both bioreactor approaches, a critical issue is the hydraulic load. Any reduction that can be achieved in hydraulic load would increase the efficiency. The daily load per 100 persons is 17,600 kg of wastewater, of which graywater is 85 percent. The major graywater contribution comes from bathing showers. The U.S. Navy's reduced flow shower development and the success of their use fleetwide in saving large quantities of fresh water is known. These units are in the Navy stock supply system and significantly reduce the generation of graywater. Current U.S. Navy efforts in the shipboard treatment of graywater depend on the continued use of the Navy-developed reduced flow bathing shower to reduce the hydraulic load.

Solid waste management on German Navy ships is affected by their mission profile which involves absence from port for no more than three weeks. Therefore, solid waste could be stored until return to port. Food is prepared on German ships in the old tradition. That means there is a lot of kitchen waste, 0.3 kg/person/day. Presently, ground kitchen waste can be discharged in the restricted zones, but it is anticipated this will not be permitted in the near future. Kitchen waste could be processed with water in a pulper, the water extracted, and the material stored for animal feed. Unless the water is extracted to 10 percent, which is difficult to do, bacterial action will quickly create unacceptable odors and the waste would be unacceptable for animal feed, but could be composted ashore. Sterilization is not effective. An ONT- sponsored effort to develop biodegradable plastics for

shipboard packaging included the successful development of odor barrier bags. These bags can contain food-contaminated plastic packaging without releasing unacceptable odors. This permits ships to hold the food- contaminated plastics which would otherwise generate such odors within three days. It is these odor-barrier bags that might make the onboard storage of pulped food waste feasible for the German Navy.

Another effort is the biological purification of oily bilge water, conducted at the NBC Defense Research & Development Center of the Federal Armed Forces at Munster. Although the German Navy is utilizing state-of-the-art oil/water separation equipment for its ships, which utilizes coalescence and gravity separation according to Stokes Law, this effort seeks to achieve the goal of oil-free bilge water through a microbiological process. Microorganisms naturally present in bilge water which are able to use diesel fuel as the sole energy and carbon source were identified. A pilot test is underway at Munster which uses these microorganisms in an activated sludge process. For bilgewater, the clarification step which separates the biomass from the clear wastewater is unique since both a floating and settling phase of agglutinating bacteria aggregates in the water. The specially developed separation stage permits the separation of water from that part of the activated sludge which is lighter and that which is heavier than water, and recirculating both parts of the sludge back into the bioreactor. The capacity of the prototype bioreactor, which was seen in operation, is approximately 1 m^3. Experimental runs were made at rates of 200 to 450 liters per day, using bilgewater containing 1000 to 2000 mg/L oil. The bioreactor was operated at 35°C, at an oxygen concentration of 2 -3 mg/L, and with 150 - 300 mg/L ammonium nitrate and 15 - 30 mg/L sodium hydrogen phosphate as macro nutrients. A reduction in hydrocarbons of 95 to 99 percent was determined. Since the discussion concerned meeting conditions for discharge into a municipal sewage treatment system, it was not clear whether this biological treatment of bilgewater was intended for overboard discharge.

The U.S. Navy has been the leader in developing shipboard environmental protection treatment systems for two decades. This is because U.S. Federal environmental legislation has been well ahead of that in the other industrialized nations, because of the high visibility of the Fleet, and because recently the U.S. have made increasingly stringent demands. Therefore, proven parallel plate gravity oil/water separators are being installed Fleetwide, small craft have small gravity separators followed by commercially available polysulfone ultrafiltration units, and the first full- scale land-based parallel plate plus ultrafiltration plant is operational at the Naval Station in Earle, New Jersey, already saving the Navy millions of dollars annually in hazardous wastewater disposal costs. However, environmental discharge standards are moving targets and it is anticipated that in the future, toxic dissolved fuel constituents of the bilgewater may have to be removed. The presently effective separation procedures can only deal with a separate phase, not with pollutants in solution. Microbiological treatment of oily bilgewater will preferentially remove the dissolved phase, because only by going into solution will the hydrocarbons become available to the microorgansims. Therefore, continued contact with the efforts at Munster is appropriate. The scientists at Munster have already applied for several patents. It appears their approach would increase its processing rate if they preceded the bioreactor treatment with a commercially available parallel plate coalescer separator.

Ships as Microcosms of Future Cities

Navy combat and tender support ships are unique in many ways which distinguishes them from other ocean-going vessels. Because of the combat mission of these ships there arise following unique

characteristics:

- High population density and personnel skill level
- Most living habits and conditions parallel shore living with obvious differences due to military constraints
- Fully equipped industrial activity for repair and maintenance
- Space is at a premium
- Hotel and food facilities experience high demand
- Most medical services must be provided
- Hotel, industrial, and operating wastes are generated
- Fresh water supply is limited.

Ships of the 21st century must comply with all environmental regulations at the local, regional, federal, and international levels. The resulting constraints and corrective steps that must be implemented will be analogous to those faced by modern industrial cities of the 21st century. These will involve

- Conservation and recycling, including manual trash separation
- Careful storage, identification, and labeling of hazardous wastes
- Segregation, disinfection, and storage of hospital wastes
- Minimization of fresh water use
- Compaction of all solid waste (store plastics, dispose rest)
- Thermal destruction of all combustible solids and concentrates
- Treatment of oily wastewater, black water, and gray water
- Prevent pollution at the source.

Accordingly, Navy ships of the 21st century represent a microcosm of the industrialized city. While there are obvious differences, there are some clear parallels that have been drawn. The implications are that whatever environmental technology is developed to provide environmental compliance may have equal application to cities, although the converse has often not been valid.

DEGREASING, CLEANING, AND SURFACE PREPARATION

There are a number of Navy maintenance and repair operations which require removal of oil and grease from surfaces.

Degreasing of Shipboard Machinery Prior to Repair in Shipyards. This is the largest hazardous waste stream generated and the most costly for disposal. It is performed by caustic washwater, by hydrocarbon solvents (VOCs), and by chlorofluorocarbon (CFCs) solvents. Use of VOCs and CFCs is being phased out due to atmospheric pollution.

Tank Cleaning. A large number of ships' tanks are repainted during overhaul operations, requiring degreasing. This also applies to all machinery spaces and the bilge. Large volumes of hazardous wastewater are generated.

Oil/Water Separator Cleaning. Ships' parallel plate oil/water separators provide full compliance with current oily bilgewater discharge regulations. With extended use, oily sludge deposits along the troughs of the corrugated polypropylene plates, gradually impairing performance. An *in situ* cleaning

procedure is needed, because access is very limited, toxic H_2S gas forms, and the manual operation is labor-intensive and hazardous to personnel. VOCs cannot be used as they would soften the polypropylene plates. An ONT-funded effort to address this particular problem is planned for FY 93.

Cleaning of Fuel Tankers. During a military emergency, the current fleet of Navy oilers may be insufficient for needed refueling operations, requiring the use of commercial carriers. Since these usually transport crude oil, the tanks of these ships would require rapid cleaning, enabling them to carry Navy distillate fuels.

Electronic Parts Cleaning. CFCs are most effective in cleaning circuit boards and other electronic parts. CFCs are being phased out due to atmospheric pollution.

As a consequence of the phasing out of the widespread and uncontrolled use of VOCs and CFCs, investigations are underway to find alternatives. One approach is to use biodegradable solvents, such as lemon oil. Another is to use the solvent strength of supercritical CO_2. Above 1100 psi and 37°C CO_2 becomes a powerful solvent for some organic materials. This has extensive use in industry, such as the removal of caffeine from coffee.

There is relatively advanced technology in Israel for degreasing surfaces, cleaning crude oil contaminated tanks and beach sand, and emulsifying crude oil and water. Professor S. Gatt of the Hebrew University - Hadassah Medical School in Jerusalem and his colleagues Professors Y. Barenholz and H. Bercovier have applied the use of specially prepared liposomes for accelerating in situ biodegradation of hydrocarbon-contaminated sand and soil, and degreasing metal surfaces. Liposomes are large amphipathic biomolecules which can be made cheaply from soy beans. These molecules behave as surfactants, being able to desorb oil from surfaces and emulsify it. Since they contain nitrogen and phosphorous, they also enhance bacterial growth and accelerate thereby the in situ degradation of hydrocarbons.

A series of laboratory degreasing experiments were conducted with a variety of metal parts provided by German companies who face an early phaseout of the currently used very effective CFC solvents. The degreasing procedure consisted of an aqueous suspension of liposomes at 55-60°C, with agitation for approximately 30-45 minutes. The liposomes, as amphipathic molecules, appeared to penetrate the grease/oil layer of the metal parts, resulting, in some cases, in a free floating grease layer. The metal parts, shipped back to the FRG, were declared completely free of grease or oil after a contract lab conducted the appropriate tests. This was considered a very successful operation to provide a substitute degreasing procedure for the current method relying on CFCs. Application has been made for a U.S. patent. Could liposomes be used for removing PCBs from the interior surfaces of ships?

Liposomes have also been used successfully to desorb crude oil from Eilat sand and emulsify it. Flasks were shown from experiments in which liposomes desorbed crude oil, emulsified it, and then enhanced bacterial activity which appeared to completely mineralize the crude oil. It was stated authoritatively that there was an insufficient quantity of liposomes to provide the sole carbon source, that a control experiment using only liposomes resulted in a bacterial population of 10^8/ml, while in the presence of the crude oil and liposomes, a bacterial population of 10^{11} to 10^{12}/ml was obtained. In addition, a C_{14} radiolabeled hexadecane experiment clearly demonstrated that the hydrocarbon was metabolized. This experiment provided confirmation that the liposomes not only desorb oil from sand and soil particles, but also enhance biodegradation by accelerating the growth of indigenous microorganisms. A field trial at a Haifa refinery is planned.

Based on the foregoing, it appears that liposomes serve as non-toxic degreasing agents, provide the means for accelerating soil slurry bioreactor degradation of fuels, as well as in situ degradation of subsurface fuel spills, and constitute a means for in situ cleaning of parallel plate oil/water separators.

At Tel Aviv University, Drs. E. Rosenberg and D. Gutnick have conducted research on microbial degradation and emulsification of hydrocarbons for 20 years. They found that surface active polymers, synthesized by the microorganisms, play a key role in these processes. Their applied work concentrated on using these biosurfactants and microorganisms on cleaning heavy crude oil deposits from the compartments of oil tankers. They have also used the biosurfactants to emulsify heavy crude oil with water, creating a 70 percent oil/30 percent water emulsion which permitted pumping without increasing the temperature of the crude oil. They have published extensively in this area. Recently, they have discovered a new microbiological procedure for treating oil pollution. The basis for this procedure is the combined use of specific bacterial strains and a unique oleophilic, slow-release, nitrogen and phosphorus source. In this procedure, the bacteria and nutrients attach to the pollutants and the nitrogen and phosphorus are released slowly on demand. This technology has been tried successfully in cleaning an oil-polluted beach in northern Israel. Over 80 percent of the heavy crude oil was degraded in one month, while the control area degraded only 20 percent. It is claimed that the formulation used consisted of specially selected bacteria and nutrients which were spread on the beach. The bacteria and nutrients attached to the pollutant, the bacteria multiplied, emulsifying and degrading the oil. Several different formulations can be prepared to suit the specific pollutant, soil type and temperature. The whole process is economical and safe, and does not require genetically engineered organisms

It appears that the researchers at Tel Aviv University have developed similar practical technology as those at Hebrew University. It is not clear which is further along and in what area. Clearly, this work is of potential practical benefit to the Navy and the DoD.

GROUNDWATER TREATMENT

Hydrocarbon fuels, chlorinated hydrocarbon solvents, and aqueous contaminants, such as nitrate (NO_3) from agricultural fertilizer, when spilled, percolate through the ground and disperse as a result of gravity and hydraulic pressure from precipitation. Remediation of the contaminants while they are still in the unsaturated zone (soil above the groundwater level) is preferred. Once that level is reached, and these contaminants dissolve in the groundwater, serious public health hazards can result. Early and rapid remediation is essential. Several emerging technologies that can provide such remediation have been identified.

Nitrate pollution of groundwater from improper use of fertilizer for agriculture is a problem in Israel as well as in the U.S. Laboratory experiments conducted by Dr. M. Green and her colleagues at the Technion - Israel Institute of Technology have demonstrated water denitrification using a small fluidized bed bioreactor. Since NO_3 is an electron acceptor, it can serve as a substitute for oxygen in microbiological processes. In the case of denitrification, a carbon source such as ethanol must be provided and the NO_3 is converted to nitrogen gas.

Although denitrification of groundwater does not appear to be a Navy environmental problem, demonstration of the fluidized bed bioreactor is potentially useful technology for bioremediation of fuel- and solvent-contaminated groundwater, as well as shipboard biological treatment of bilgewater, and hotel wastewater. The German Navy is experimenting with shipboard biotreatment of toilet,

laundry, shower, and kitchen wastewater, and both the U.S. and German navies are investigating biological treatment of bilgewater.

One of the problems with shipboard biological treatment of wastewater is the time required for the biological activity, because the limited space does not permit a large enough surface- to-volume ratio for efficient contact between biomass and substrate. This problem is overcome with the fluidized bed bioreactor, because Dr. Green reports a reaction rate corresponding to a retention time of less than three minutes! This is in part due to both the carbon source and the electron acceptor being dissolved so that there is a single phase. In the biodegradation of shipboard wastes part of the carbon source will be dissolved and part will be in suspension. Dr. Green's work has also demonstrated procedures for preventing aggregation of the sand particles supporting the microorganisms, as well as excess biomass removal. Consequently, the reactor is characterized by efficient contact between biomass and substrate, a high biomass concentration and the absence of clogging and channeling often experienced in fixed beds, eliminating the need for backwashing. A paper has been prepared and submitted for publication in the Water Research Journal. In addition, a full scale unit is planned together with an industrial company in Israel. This technology may be effective in specific shipboard applications like the treatment of graywater. Navy research on shipboard graywater treatment using ultrafiltration (UF) has found that the biological oxygen demand (BOD) of the effluent has not been sufficiently reduced, because a good portion of the BOD is dissolved and therefore not retained by the UF membrane. Other potential applications are in the use of on site bioreactors for treating hydrocarbon contaminated water from aged underground fuel spills; pierside treatment of bilgewater that has not been sufficiently processed by the onboard liquid/liquid separation systems, which are meeting current standards, but may not be fully effective in the future; and the on-barge treatment of toxic sediment harbor from dredging operations, a very large disposal problem in the near future.

When volatile organic compounds (VOCs) such as gasoline, JP-4 fuel or trichlorethylene have contaminated groundwater, remediation may be accomplished with technology being developed by Dr. H. Gvirtzman of the Hebrew University of Jerusalem, Dr. K. Yakov of the Ministry of Agriculture in Israel, and Dr. S.M. Gorelick of Stanford University, U.S.

Their proposed procedure consists of an ingenious combination of the established technologies of air-lift pumping and vapor stripping. A well is drilled to the contaminated groundwater. This well is perforated to allow contaminated water to flow into it. An eductor pipe is installed inside the well casing, creating a well within a well. The eductor pipe is perforated beneath the water table to allow water flow into the "inner well." It is solid elsewhere. Inside the eductor pipe, an air line is introduced and air injected. The air is released beneath the water table, creating bubbles that rise. The eductor pipe is slotted and baffled to prevent gas bubbles from escaping horizontally. With this configuration, it is impossible for air bubbles to enter the aquifer, because the bubbles are fully contained within the eductor pipe. Due to the density difference between the water column outside the well and the water-bubble mixture column inside the inner-well, a lift is created. In other words, water and air rise towards the ground surface within the eductor pipe, forcing additional water to flow from the aquifer into the eductor pipe. The water and air bubble mixture flow upward in the annular space around the air line.

At the top of the well, the gaseous phase is separated from the water phase. A simple deflection plate forces the water-bubbles mixture into a large cylinder in which they rest. The air bubbles are released into the cylinder upper space, from which they are drawn. In this system, water is not lifted to the ground surface, thereby reducing costs and protecting the biotic environment above the root

zone. The water is permitted to flow into the unsaturated zone through a series of drains that are installed beneath the ground surface in the unsaturated zone. These drains emanate horizontally from the well and their purpose is to return the air-lifted water to the aquifer by allowing the water to infiltrate through the unsaturated zone. In this way, a water circulation cell is created in the vicinity of the well.

Simultaneously, an air-stripping chamber is created within the eductor pipe. During the period in which the air bubbles flow through the water in the well, VOCs are transferred from the water to the gas phase due to a concentration gradient. The air bubbles, including the VOCs are collected using vapor extraction techniques at the top of the well. The organic rich air can then be treated using existing methods.

Figure 7 illustrates operation of the remediation cell under steady state conditions. In this figure, water (solid arrows) is lifted in the well, forced into the unsaturated zone, infiltrates to the aquifer, and flows back to the well. Air (outlined arrows) is injected into the well, bubbles rise, and are collected at the top of the well. The foregoing description and figure are taken from a paper by Drs. Gvirtzman and Gorelick, "The Concept of In Situ Vapor Stripping for Removing VOCs from Groundwater" which is in press in Transport in Porous Media.

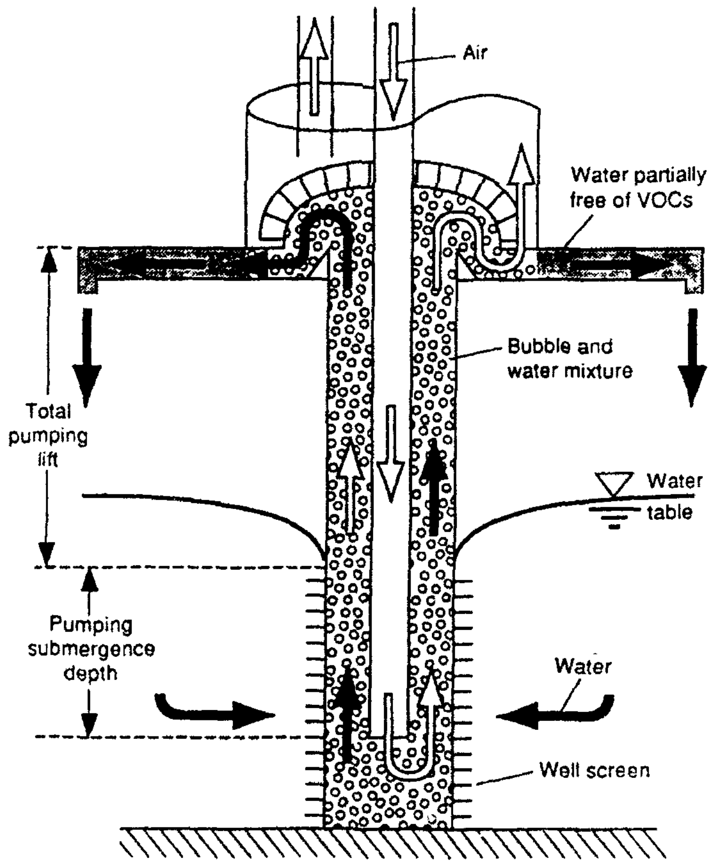

Figure 7. The Remediation Circulation Cell Under Steady State Conditions.

The feasibility of the proposed method was analyzed using concepts of mass transfer of VOCs like trichlorethylene from water to air bubbles. Calculations indicate that the method has promise because equilibrium partitioning between the contaminated water and the gas bubbles is rapidly established. Israel faces a serious problem with its water supply which is being depleted due to overpumping and degraded in quality from coastal salt water intrusion. In addition, leaks and accidents from hydrocarbon storage tanks and pipelines along the coastal plain aquifer are further endangering the quality of the groundwater. It is expected that this procedure will quickly be evaluated in the field.

As stated in the section on *In Situ* Bioremediation, the U.S. Navy and Air Force have thousands of sites contaminated with hydrocarbon fuels. As long as the fuel remains in the unsaturated zone above the groundwater, the currently accepted procedure is to use bioventing. In those cases where fuels have passed through the unsaturated zone and have reached the water table, the need for rapid remediation of the groundwater could be achieved by the new procedure just described. In addition, the Air Force has a serious trichlorethylene contamination problem at a number of sites and could achieve remediation by this procedure, if the TCE had reached the groundwater level.

HEAVY METALS REMOVAL

Current wastewater treatment processes are not effective in removing toxic heavy metals to concentrations sufficiently low to comply with anticipated amendments to the Clean Water Act which will have an impact during the late 1990s and the 21st century. A number of potentially effective biological materials are being investigated to provide such treatment. These materials are algae, yeast cell walls, bacteria cell walls, chitosan, plants such as azolla, and fungus. The principle that makes these biological materials effective chemical binders of heavy metals is the presence of carboxyl groups in polysaccharides and amine groups in protein structures. What needs to be determined is which single material or combinations are most effective, what are the limitations and what are the economics of this approach. The use of specially prepared dry algae for heavy metal removal has been developed in the U.S. to the pilot demonstration stage with the support of the EPA.

The following research approaches have been proposed:

- Use of bacteria for removal of toxic heavy metals. A large number of bacteria are capable of chemically binding metals. One has been identified as being especially effective in binding cadmium and mercury. This bacterial strain is easily and economically grown. No quantitative information has been made available. Dr. E. Rosenberg and Dr. E. Z. Ron, Tel Aviv University.
- Biofiltration using the aquatic fern Azolla was demonstrated effective for dilute and concentrated effluents (ppm to 10^4 ppm) of Cd, Cr, Ni, Pb, Hg, Cu, and UO_2. This approach was successful with seven industrial effluents, and evaluated on site for Cd, Ni, Au, Pt, and Pd industrial operations. U.S. Patent 5,000,852 was granted 3/31/91. Dr. E. Tel-Or, Hebrew University of Jerusalem.
- Toxic metal removal and recovery using spent yeast biomass. The yeast is a waste byproduct from beer breweries. It must be processed, as only the cell walls have metal binding capability. Further, the cell walls must be immobilized on micro glass beads by a salinizing technique to provide adequate flow rates. This approach appears promising, but no quantitative data demonstrating effectiveness has been made available. Dr. S. Yannai, Technion Institute.
- Toxic metal removal and recovery using sp Penicillium fungi biomass. Published data on

removal from solution of uranyl chloride (UO_2Cl_2), with 90 percent removal from a 1 ppm solution and capacity of 5000 ppm under relatively severe conditions of 40 to 50°C and pH 2.5 to 9.5. This adds to a growing body of interdisciplinary information on the interaction between fungi and metals or minerals. Recovery of the U to nearly 99 percent with extraction by $(NH_4)_2CO_3$ and by $NaHCO_3$ permitting reuse of the biomass was demonstrated. There is also published data on the biosorption of Pb, Cr, Fe, and Cu. U.S. Patent 4,732,681, Removal of Contaminants, dated 22 March 1988, also claims removal of Ni, Zn, and Cd. Dr. M. Galun, Tel Aviv University.

The most promising approaches are those able to remove a mixture of heavy metals from a treated (2nd stage) sewage effluent well below anticipated early 21st century discharge limits as well as removal of specific heavy metals at the source prior to release to the treatment plant. Removal of heavy metals at the source, as at a metal plating facility, is preferred and needs to include recovery of the biosorbed metals for recycling.

FIRE FIGHTING TECHNOLOGY AND ENVIRONMENTAL COMPLIANCE: IONIZED FLAME VAPOR GUN

Fire on a military ship at sea loaded with fuel and ammunition is a very dangerous matter. The Navy trains thousands of sailors annually to fight shipboard fires. Effective training requires realistic conditions of flame, heat, black smoke, and chemical fire fighting agents. This generates air and water pollution. Many fire fighter training facilities operate under temporary wavers from local regulatory agencies and are under threat of fines and closure, because they are consistently in violation of local regulations. Short-term efforts to respond to this problem are underway. A longer-term solution might be to change the method of extinguishing such fires.

Conventional methods of extinguishing fires are slow and not effective for intense fires. Delay in extinguishing shipboard fires due to intense heat and opaque smoke threatens the lives of trapped personnel. One current Navy development effort seeks rapid filtration of the black smoke to restore visibility so fire fighters can locate personnel and the source of the blaze. A potentially new approach for very quickly extinguishing intense fires on miliary vehicles (tanks), aircraft, and ships has been advanced by Dr. Y. Goldman of the Faculty of Aerospace Engineering at the Technion - Israel Institute of Technology is a specialist on combustion and propulsion.

Physical principles of stopping the combustion process are based on elimination of four necessary conditions for flame existence and propagation:

1. Availability of oxygen around the fire source
2. Flame stabilization factors
3. Availability of free radicals at the flame front, and
4. Heat transfer conditions, providing thermodynamic equilibrium between the fire source and surroundings.

Absence of ONE of these factors is sufficient to stop the fire. The first two conditions are the most important. Difficulties in using conventional methods for oxygen or air flow restrictions to the flame area correspond to the problem of delivering a large amount of oxygen-free gas, like nitrogen or steam. Halogenated fire-suppressants such as the very effective "Halon" must be phased out in accordance with the Montreal and London protocols to protect the atmospheric ozone layer.

Doctor Goldman's idea and proposal is to use an oxygen-reduced air-water mixture "blow" to suppress flame stabilization points and to stop the fast fuel oxidizing process. The idea is to accelerate ionized flame by an electro-magnetic field. The flame will be used to remove oxygen from atmospheric air, to produce ions, to transform heat into dynamic energy of the jet, and to evaporate part of the water spray that has been injected into the jet. Blowing toward a fire source the mixture will result in the creation of a large region filled with a gas under the lean limit of flammability. A short period of exposure to the jet is sufficient to stop the fire.

In this case, a joint U.S. - Israel development program appears appropriate, if this idea is favorably accepted by those concerned with fire fighting development. Since this concept potentially benefits the other services, a unified tri-service endeavor is advised.

The following two sections deal with the environmental activities of two supra-national organizations. Their activities are different and extensive in their potential impact. More attention needs to be paid to these organizations than there was time in this study. A separate assessment and analysis is justifiable.

NATO: COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY

The Committee on the Challenges of Modern Society (CCMS) was established in 1969 with the aim of engaging in practical problems at the international level that were already being studied at the national level and, by pooling existing expertise and technology, arriving relatively rapidly at conclusions and recommendations that would benefit member nations. In 1990 it was agreed that the CCMS should expand and invite experts from Central and Eastern Europe to participate in CCMS workshops, conferences, and seminars. While the CCMS is involved in a number of social challenges, none is as significant as that of environmental concerns and ecological effects of military activities.

The CCMS' mandate is to improve in every practical way the exchange of views and experience among the Allied Countries in the task of creating a better environment for their societies. It considers specific problems of the human environment with the deliberate objective of stimulating action by member governments. Consequently, the CCMS does not engage in any research activities and its work is carried out on a decentralized basis. No program funds for CCMS activities were made available through the NATO budget. It carries out its mission through pilot studies. As of June 1991, 37 pilot studies were completed and 22 were underway. Proposals for studies are made by the nations themselves and are based on the identification of environmental problems which lend themselves to international cooperation as well as the availability of funds to conduct the study. No member country is required to participate in any study. Each country is free to choose where best to apply its resources and expertise. However, results are available to all. Emphasis is placed on projects which can guide policy formulation and stimulate domestic and international action. The results of the Committee's studies are available to institutions and individuals on a world-wide basis.

A number of new studies are underway:

- Protection against marine biological fouling
- Sea-lagoon interaction
- Dose-response analysis and biologically-based risk assessment for initiator and promoter carcinogens

- Impact on people and the environment of the agricultural use of pesticides
- Reduction of air pollution from marine engines
- Pollution prevention strategies for sustainable development
- Use of simulators to reduce environmental damage caused by military activities.

A list of 1992 CCMS meetings that were held follows:

- Air Pollution Transport and Diffusion over Coastal Urban Areas, Athens, Greece, February 6-7
- Dose Response Analysis and Biologically-Based Risk Assessment for Initiator and Promoter Carcinogens, Washington, U.S., February 11-14
- Applicability of National Environmental Expectations and Requirements on NATO Activities, Vancouver, Canada, March 9-13
- Use of Simulators as a Means of Reducing Environmental Damage Caused by Military Activities, Munster, FRG, March 31 - April 1
- Estuarine Management (Phase II), March
- Aircraft Noise in a Modern Society (Follow-Up), Berlin, FRG, April 14-16
- Desertification in Developed Areas, April

Two recent CCMS/EPA meetings have resulted in proceedings: "The Role of the Military in Implementing the Montreal Protocol," Williamsburg, VA, September 11-13, 1991; and "Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater," Washington, DC, November 18-22, 1991.

A CCMS pilot study on "Promotion of Environmental Awareness in the Armed Forces" concluded that the Armed Forces take action on known problems where solutions are known; many problems are unique and solutions are not known. The implication is that while environmental awareness has been raised, in many cases solutions are not available. In view of the relative detente in Europe, one can expect significantly reduced military exercises as one means to reduce environmental impact. A further long-range solution may be the use of combat simulators, which will be explored in a forthcoming meeting.

Contacts at NATO are Dr. Deniz Yuksel-Beten, Director of NATO's Committee on the Challenges of Modern Society (CCMS) and Mrs. Marshall Carter Tripp, Science & Environmental Affairs Officer, U.S. Delegation to NATO.

COMMISSION OF THE EUROPEAN COMMUNITIES

Directorate-General — Science, Research, and Development

Commission funding for environmental research has risen from 6.3M ECU (European currency unit = $1.35) in 1973 to 260M ECU in 1992. This program (1991-1994) is aimed at contributing to the scientific and technical basis for the implementation of EC environmental policy. It is an extensive and apparently well funded program. It is divided into the following areas:

1. Participation in Global Change Programs

    - Climate change and climatic aspects

- Global changes in atmospheric chemistry and biochemical cycles and their consequences for life on earth

2. Technologies and Engineering for the Environment

   - Assessment of Environmental Quality and Monitoring
   - Technologies for Protecting and Rehabilitating the Environment
   - Major Industrial Hazards
   - Environmental Protection and Conservation of Europe's Cultural Heritage

3. Research on Economic and Social aspects of Environmental Issues

4. Technological and Natural Risks.

A more detailed outline of Area II, Technologies and Engineering for the Environment, is provided in Appendix B. Demonstration (pilot and full scale) projects are not funded by the Commission, because that could lead to giving the funded organization an unfair economic advantage. The Commission will not do anything that can be done better at the national level. When a project is funded, it must be performed by at least two member nations. This is intended to promote cooperation and interaction between member nations. Research projects must also contribute to the economic competitiveness of the EC worldwide.

Since funding for this program is distributed to the European countries, the EC Program provides a means for stay'ng current with environmental technology research in Europe. One contact is Dr. Canice Nolan, Scientific Officer, Commission of the European Communities.

SUMMARY AND CONCLUSIONS

Selected visits were made to the Federal Republic of Germany (FRG), the United Kingdom (U.K.), the State of Israel, and two supra-national organizations, the NATO Committee on the Challenges of Modern Society and the Commission of European Communities. In all, 25 organizations were contacted. The visits were interactive, that is, they did not merely consist of receipt of information, but often involved questions and detailed discussions. In most cases, I made a presentation of Navy environmental R&D, having previously provided a list of presentation topics. Appendix C lists the individuals contacted at the various organizations visited. It was an intensive endeavor. While much technology was identified, much remains to be found. The Table of Contents to this report identifies the technology topics encountered and discussed. All of these topics fall under the DoD environmental requirements listed in Appendix A. The continuing theme throughout this report has been the need and importance of developing affordable environmental technology.

United States environmental compliance legislation, which drives technology development, is years ahead of European legislation. However, the gap is closing rapidly in recognition of the environmental damage that can result. This is especially dramatic from the recent discoveries of the consequences of uncontrolled industrial activity in Eastern Europe. The following general conclusions are drawn:

- Environmental technology research is increasing as a result of increasingly stringent legislative requirements in Europe.

- Much of the research emphasizes measurements, diagnostics, impact assessments, and numerical modeling.
- Research is growing in means to repair damage and prevent pollution.
- In the FRG, there is a strong effort underway to demilitarize ordnance and remediate soil contaminated by ordnance testing and manufacturing.
- Research efforts by the European Community emphasize environmentally sustainable development for enhanced economic competitiveness.
- Pollution prevention research in the FRG is focusing on electroplating and paint application manufacturing processes to significantly reduce or eliminate hazardous waste generation.
- Environmental technology research in Israel lags behind European activity; however, effort is increasing rapidly because it is a small country with a fragile ecosystem, limited fresh water supply, and a high concentration of scientific and technical personnel.

RECOMMENDATIONS

There is much environmental technology and science research underway in the United States by the EPA, the Navy, Air Force, Army, the DOE, other government agencies, including state agencies. In order to respond effectively and reverse pollution of our groundwater, soils, air, marine, and fresh water we need a series of affordable environmental technologies to transition to implementation between now and the next 5 years. Continued detailed tracking of foreign technology remains an important part in avoiding wasting our resources through duplication and maximizing international synergism in environmental research. This will aid our effort to protect our environment while maintaining and even expanding our economic position world wide, currently known as sustainable development.

Specific recommendations are:

- Much of the technology discussed in this report has potential application throughout the Department of Defense. Department of Defense Project Reliance has expanded its sphere of interest to include international R&D assessment. Continued examination of environmental technology by ONR Europe and ONRASIA can provide information to Project Reliance.
- Research projects sponsored by the European Community (EC) should be carefully followed. In addition, ONR Europe should arrange for a 2 week EC visit by a liaison scientist to fully assess environmental research being sponsored.
- Efforts of the NATO Committee on the Challenges of Modern Society (CCMS) should be followed. While this is not sponsored research, it does involve the work of multi-national committees. Study topics of particular interest are:

    - Use of simulators to reduce environmental damage from military activities
    - Pollution prevention strategies for sustainable development
    - Protection against marine biological fouling
    - Sea-lagoon interaction
    - Reduction of air pollution from marine engines

- Pollution Prevention efforts in electroplating and paint application by the Fraunhofer Institute should be followed further by close examination of manufacturing details and related to state-of-the-art practices in the U.S.

- Research on domestic and industrial waste management and recycling at the Technical University of Aachen should be followed for application to military base operations.
- Results from research on *in situ* hydrocarbon bioremediation by the University of Karlsruhe should be evaluated for application to jet fuel remediation. There are several empirical insights from that work that might benefit the Navy and Air Force to bioremediate fuel-impacted sites.
- In addition to a resident liaison scientist in environmental technology at ONR Europe, short-term residencies in specifically defined research areas should be considered.
- Environmental biotechnology research at the GBF in Braunschweig should be closely followed. The GBF is probably the foremost biotechnology research group in Europe.
- In view of the strong Congressional interest in environmental technology in Israel (see Introduction), tracking results in that country is advised; if Congress prescribes interaction, we should be ready to propose that technology of greatest value to the Navy and DoD.

Appendix A

DEPARTMENT OF DEFENSE ENVIRONMENTAL REQUIREMENTS STRUCTURE

(Note: the numbers in parentheses designate the line items devoted to that sub-subcategory.)

PILLAR 1 - CLEANUP

A. Expeditious, Affordable Remediation Technologies

- Groundwater (10)
- Sediment (5)
- Sludges (2)
- Soils (16)
- Structures (5)
- Surface Water (5)

B. User-Based Risk Assessment Methodologies

- Fate and Transport (11)
- Effects Data (7)

C. Improved Site Characterization and Monitoring

- Field Sampling (16)
- Sensing (6)
- Database Development (4)

PILLAR 2 - COMPLIANCE

A. Satisfy Clean Air Act Provisions

- Control Emissions (Primary Pollutants, VOCs, toxics) (16)
- Sampling and Monitoring (11)

B. Satisfy Clean Water Act Provisions

- Control Discharges (15)
- Sampling and Monitoring (10)

C. Satisfy Resource Conservation and Recovery Act Provisions

- Treatment — Incineration, Thermal, Biological, Chemical (10)
- Storage — Underground Fuel Tanks, Container and Conforming (4)
- Disposal — Land and Deep Well (6)
- Administration — Base Closure Plans, Characterization (3)
- Sampling and Monitoring (2)

D. Noise

- Assessment and Modeling (12)
- Impact Mitigation (6)
- Measurement and Monitoring (2)

E. Other Regulations — TSCA, ESA, MPRSA, NEPA, FIFRA (23)

F. Support Responsible Regulatory Standards

- Effects Data (1)
- Fate and Transport Models (4)

PILLAR 3 - POLLUTION PREVENTION

A. Reduce Hazardous Waste by 50 percent by 1997 From Baseline 1992

- Machine and Metal Work (4)
- Cleaning and Degreasing (7)
- Metal Plating and Surface Finishing (9)
- Painting and Coating (7)
- Paint Stripping (8)
- Ordnance Manufacturing (8)
- Ordnance Demilitarization (2)
- Shipboard Effluents (8)
- Pesticides, Herbicides, and Rodenticides (2)
- Non-Point Source Pollution
- Other Waste (9)
- Composite Material (1)

B. Eliminate Need to Purchase Ozone-Depleting Substances by End of 1995

- Refrigerants (5)
- Foams (1)
- Solvents (4)
- Firefighting Agents (5)
- Aerosols (1)
- Sterilents (1)

C. Develop Environmentally Sound Weapons Systems and Platforms

- Concept Development (1)
- Design (7)
- Test and Evaluation (2)
- Operations (1)
- Maintenance (1)
- Disposal (3)
- Fate and Effects (1)

D. Reduce Solid Waste 50 percent by 1997 (vice 1992) for Land and Zero Plastics Discharge from Ships by 1998

- Trash and Construction (10)
- Water Treatment (1)
- Shipboard Effluents (3)

E. Reduce Greenhouse Gas Emissions

- Measure Contributions to the Atmosphere (4)
- Develop Control Strategies (7)

F. Alternate Fuels

PILLAR 4 - CONSERVATION AND STEWARDSHIP

A. Predicate Use Planning and Real Property Management Decisions on Natural and Cultural Resource Capabilities and Constraints

- Natural and Cultural Resource Baseline Data (5)
- Carrying Capacity (6)
- Environmental Impacts from Training and Testing (5)
- Land Scheduling and Management Systems (4)
- Land/Range Design and Improvement (4)
- Erosion Control (4)
- Water Quality (3)
- Cultural Resources and Historical Site Management (4)
- Forestry Management (2)

B. Protect the Biological Health of the Environment

- Wetlands (4)
- Coastal Zone (4)
- Marine and Harbor (3)
- Forest (5)
- Other "Sensitive" Ecosystems (2)

C. Improve Protection of Threatened/Endangered Species and Marine Mammals

- Training and Testing Impact Analysis (2)
- Critical Habitat Requirement (1)
- Species Management and Protection (7)
- Species Propagation and Recovery (3)
- Habitat Management (6)

Results of the environmental technology research described in this report fall under Pillar 1 Cleanup, Pillar 2 Compliance and Pillar 3 Pollution Prevention.

Appendix B

EUROPEAN COMMUNITIES R&D PROGRAM IN THE FIELD OF ENVIRONMENT AREA II — TECHNOLOGIES AND ENGINEERING

A sustainable development within the European Communities in the future will depend to a large extent on the capacity to minimize environmental damage. This goal requires efforts in two directions:

1. Elaboration of reliable, fast, and economical methods for the surveillance of the environment and design of appropriate equipment for monitoring purposes.
2. Development of advanced techniques and systems to protect and rehabilitate the environment.

In addition, research on the reduction of major industrial hazards and on the protection and conservation of the cultural heritage is included in this area.

II.1. ASSESSMENT OF ENVIRONMENTAL QUALITY AND MONITORING

The program will have to react to new specific requirements derived from the implementation of the Community environmental policy; hence, enough flexibility is necessary to ensure a fast response to changing policy needs. The work program to be established for the European Environment Agency being set up will certainly identify new research requirements in addition to those outlined here.

II.1.1. Objectives

At present, research on assessment of environmental quality and monitoring will address the following objectives:

- Development of measurement techniques and instrumentation to elucidate tropospheric chemistry
- development of methods and instruments for the measurement of stratospheric trace constituents related to stratospheric ozone depletion
- design and operation of a smog chamber working under natural sunlight for experimental studies on the formation of photochemical oxidants
- development of analytical techniques for the determination of low concentrations of organic pollutants and their conversion products in the aquatic environment
- development of biosensors and/or improvement of their performance.

II.1.2. Research Tasks

1. Development of measurement techniques and instrumentation to elucidate tropospheric chemistry.

   The main emphasis will be given to:

   - development of fast response and high sensitivity instruments in particular to be used on airborne platforms

- development of integrated instruments for the simultaneous measurement of different parameters
- intercomparison of methods for sampling and analysis.

Measurements will concern species related to acid deposition and to pollution by photochemical oxidants and molecules associated with long-term atmospheric changes ("global change"), such as hydrocarbons, nitric acid, and aerosols.

2. Methods and instruments for measuring important atmospheric constituents in the stratosphere.

Based on the needs identified within the ongoing research program, the improvement or development of measurement techniques for ClO, BrO, N_2O_5, OH and HO_2, as well as atmospheric process, will have priority and comprise:

- ground based instruments and measurement techniques for long-term monitoring,
- airborne measurements with high temporal and spatial resolution
- spaceborne measurements closing gaps in the spectral detection range of satellite-borne sensors and improvement of their performance.

In detail, the following problems should be addressed:

Ground based measurement

- Automation of instruments
- development of self-calibrating systems
- development of portable calibration standards with long-term stability
- intercomparison of instruments used in networks
- improvement of altitudinal resolution of LIDAR measurements and of particle measurement techniques to discriminate various types of aerosols.

Airborne measurements'

- Definition of design parameters to ensure compatibility of different instruments on different platforms
- development of small and economic sensors with high temporal resolution
- improvement of angular stability of optical instruments
- adaptation of laboratory instruments to stratospheric conditions and to the requirements of platforms.

Spaceborne measurements

- Design studies for sensors for ozone, nitrogen oxides, oxides of chlorine and bromine, hydrocarbons, CFCs, HCl, HF, and other relevant species
- design studies for remote sensing systems for the detection of OH radicals
- improvement of interpretation and validation of satellite data.

3. Design and operation of a large smog chamber working under natural sunlight.

Smog chambers using natural solar radiation are considered as an essential tool to study the formation of photochemical oxidants, permitting, e.g., the study of Diesel exhausts or the emissions from burning alternative fuels under realistic experimental conditions.

Exploratory studies on a "European Photoreactor" (EUPHORE) have resulted in a project aimed at:

- Design, construction, and operation of an "outdoor" smog chamber operating with natural sunlight, permitting experiments with real emission sources, in particular cars
- implementation of complementary laboratory investigations related to ozone, photo-oxidant, and particulate formation.

The project is in close relation to work on tropospheric chemistry under research area I subarea 5.

4. Analysis and fate of organic pollutants in water.

Among a great number of chemicals used in agriculture which may pollute ground and surface water bodies used for drinking water production, pesticides deserve particular attention as a consequence of the implementation of Community regulations of pesticides on drinking water quality, setting severe statutory maximum concentrations to protect human health.

Main emphasis will be given to the development of sensitive and specific analytical techniques for widely used pesticides and their degradation products, complemented by investigations of the behavior of pesticides in water treatment processes.

5. Development of Biosensors.

Two groups of biosensors are of importance in the field of environmental protection to solve environmental measurement problems for which conventional measurement methods are of an inferior performance:

- Sensors with high sensitivity and selectivity for specific chemicals and with low cross-reactivity, normally based on exzymatic reactions
- biosensors which allow a direct quantification of the biological/toxicological effects of the pollutants in specific environmental compartments such as groundwater.

Work will stress the development of biosensors offering a clear advantage in terms of sensitivity, selectivity, response time, and cost compared to physical/chemical methods, in particular for *in situ* measurements; it will address their application for monitoring of the emissions to and pollutants (such as pesticides, nitrate, phosphate, and heavy metals) in surface, ground and drinking water. and soil.

Basic work will be complemented by research into specific sampling and measurement procedures and development of field instrumentation.

6. Improvement of acoustic measurements of environmental significance.

II.2. TECHNOLOGIES FOR PROTECTING AND REHABILITATING THE ENVIRONMENT

The Community Environment Policy evolved in recent years from setting quality objectives and standards to an active approach to environmental management. In particular, the policy related to waste, recently has been clearly defined and is being implemented through various approved or proposed specific directives.

The role of research in support of this policy is self-evident. Furthermore, the importance of the research programs as a "precursor" to existing or planned pilot demonstration activities needs to be mentioned.

II.2.1. Objectives

The general objectives of research in this field are:

- The promotion of "cleaner technologies" defined as new or modified processes aiming at less emissions, less waste, and/or less consumption of raw materials and energy
- the improvement of abatement technologies for emissions to the atmosphere
- the introduction of new waste water treatment systems, permitting the reuse of process water
- recycling of waste with emphasis on toxic and dangerous waste
- the promotion of methods for treatment and safe disposal of waste
- the investigation of suitable practices for the restoration of abandoned disposal sites and contaminated areas.

II.2.2. Research Tasks

1. Cleaner technologies.

The sectors with high priority for future research are the chemical, pulp and paper, and food industries. Special attention will be paid to activities such as industrial cleaning.

Emphasis will be given to:

- Process optimization based on numerical simulation
- substitution of harmful or toxic substances, in particular VOC's
- appropriate selection or precleaning of raw materials
- development of closed loops in individual process steps, e.g. for process water
- development of specific process-integrated purification steps
- on-line process control in order to increase efficiency and to reduce emissions,

- development of early warning systems with a feedback to process-specific mass flow patterns, including the development of suitable sensors and/or biosensors.

2. Emission abatement technologies for emissions to the atmosphere.

   Research will concentrate on:

   - The reduction of gaseous and particulate emissions from stationary sources, e.g. small heat and/or power producing units and incinerators
   - improvement of catalytic end-of-pipe technologies for stationary sources, with emphasis on volatile organics and halogenated hydrocarbons
   - improvement of abatement technologies such as filtration and biofiltration including appropriate filter regeneration techniques.

3. New waste water treatment systems.

   The following topics will receive priority:

   - Optimization of flow patterns for integrated nitrogen, phosphorus and BOD removal, and development of techniques and sensors for process control and monitoring
   - development of improved physical and chemical separation techniques for contaminants in waste water streams originated from different municipal or industrial sources
   - research on disinfection and storage of residual water, taking into consideration odors, nuisances, and sanitary risks in view of its reuse, e.g. for irrigation.

4. Recycling technologies.

   In line with the general principle to favor recycling instead of waste disposal, methodological research will cover the whole life cycle of products, including their collection and the separation of components and materials. Priority will be given to the recycling of products and of wastes originating from industrial processes with emphasis on toxic and dangerous waste, including:

   - Recycling of plastic materials (thermo- and non-thermo plastics)
   - recycling of composite materials, e.g. electronic equipment, printed circuits, etc.
   - recycling of solvents and other toxic dangerous products (excluding non-ferrous metals, handled within the Industrial and Materials Technologies Program).

5. Treatment and disposal of waste.

   In order to promote safe disposal of wastes not amenable to recycling, pretreatment of residues is essential, requiring research on:

- Stabilization of waste and reduction of its volume, detoxification of toxic industrial waste, including biological treatment with natural and engineered organisms,
- evaluation and development of monitoring, sampling, and analysis methods for the management and control of waste disposal sites
- description and modelling of degradation processes and mass balances.

6. Risk assessment for and restoration of abandoned disposal site and contaminated industrial sites.

   Research will extend to:

   - Development of rapid non-invasive methods for locating and measuring contaminants and improvement of existing techniques in terms of effectiveness and cost
   - development of *in-situ* sensors for appraisal and long-term monitoring of contaminated sites including the adaptation or the development of sensors
   - study of adsorption/desorption processes, pathways and bio-availability of pollutants, and modelling and predicting their behavior in contaminated sites
   - assessment of human exposure to mobilized soil contaminants.

II.3. MAJOR INDUSTRIAL HAZARDS

A number of spectacular accidents on industrial production sites affecting severely the general population and the environment in their surrounds led to Community regulations ("Seveso" Directive) with similar objectives as those on sites with nuclear activities.

In parallel, research activities to develop a better understanding and knowledge base for the identification of accident hazards and assessment of their risk to the general population and the environment from major industrial operations were initiated. A substantial effort on their continuation is required.

II.3.1. Objectives

Development of technologies for preventing and mitigating accidents and support to regulatory activities, derived from Council Directive 82/501/EEC, anticipating also future policy developments.

This topic focuses on 3 themes of primary concern:

1. Developing technologies for accident prevention and environmental restoration
2. Improving the understanding of the chemical and physical hazard phenomena
3. Improving the understanding to managing risk.

II.3.2. Research Tasks

1. Technologies for accident prevention and environmental restoration.

A better fundamental understanding is necessary of the mechanisms of prevention and mitigation means. Technological developments could be applicable to either plant or transport systems. The approach to be taken can be summarized as follows:

- Development of alternative low-hazardous operations and ways of reducing inventories in hazardous processes
- development of early-warning systems and direct detection systems for quantifying hazards
- development of inspection and maintenance technologies
- identification of industrial best-practices and development of tests for improving the design and construction of materials
- improvement of the reliability of technologies and assessment of the effectiveness of improvements
- development and improvement of procedures for characterizing the hazards of chemicals and reaction mixtures
- evaluation, development, and optimization of mitigative technologies
- examination of the technologies and logistics to protect operations from hazardous occurrences
- development of technologies and logistics to decontaminate accident areas.

2. Chemical and physical hazard phenomena.

Research so far has concentrated and needs to continue on a restricted number chemicals used, stored, and transported in large quantities. Other chemicals and new energy sources also raise a number of previously unforeseen problems. To achieve the outlined objectives, the following research subjects will need addressing:

- Multiphase release of toxic and flammable materials interface with atmospheric dispersion phenomena including dispersion from a time-varying source
- unconfined vapor-cloud explosions in complex obstructed areas
- shock wave interaction with structures and quantification of the explosive hazard presented by energetic substances
- short, medium, and long-term toxicological effects from the short exposure to high concentrations of toxic products
- prediction of products generated from large industrial fires and how they are dispersed
- fire propagation in industrial buildings and industrial sites, and in transport
- damage to industrial sites from dust explosions
- determination of the uncertainty in the predictability of models and development of validation procedures.

3. Risk management.

A better understanding of how to manage industrial risk is required. The topic is very broad and the following approach identifies the more important tasks:

- Transfer of research developments into methodologies and tools of assessment, and validation procedures for software and existing failure-rate data bases
- analysis of, and trend identification in, accident causes and examination of how accident and near miss data can be more effectively recorded
- development of auditing systems to assess the ability of industries to operate safely and with concern for the environment
- determination of industrial best practices and formation of organizational codes of practice and examination how industry conforms with safety standards
- modelling and validation of communication processes, examination of decision-making processes and development of emergency, planning procedures
- examination of organizational behavior and change during a crisis, i.e. cognitive task and analysis, task responsibility, training tools
- development of models of human and group behavior and effect on company culture
- examination of regional/national variations in safety culture and managing risk
- examination of the human tolerance of risk and analysis of the social benefit/detriment of industrial operations.

II.4. ENVIRONMENTAL PROTECTION AND CONSERVATION OF EUROPE'S CULTURE HERITAGE

The protection and conservation of Europe's cultural heritage is recognized to be of utmost importance by all Member States and subject of a Community policy to be progressively defined. Historic buildings, sites, monuments, stained glass, wall coverings, mural paintings, paper, and archives have suffered from extensive deterioration from "environmental" aggression.

Although substantial interest has developed in the scientific community on research into the preservation of cultural property under the EC program, a number of basic questions remain to be answered, such as:

- Environmental and deterioration history of cultural properties
- effectiveness and cost/benefit of previous conservation strategies,
- agreed definition of damage.

II.4.1. Objectives

The overall objective is to provide substantial support to the development of a scientific basis for environmental protection, restoration, and conservation of European cultural heritage.

II.4.2. Research Tasks

1. Cultural materials, environmental factors, damage definition, and measurement.

   The aim is to identify and assess quantitatively the relationships between environmental factors and damage to cultural property in such a way as to provide an

improved scientific basis for their environmental protection. Projects will be based on suitable combinations of *in situ*, standardized field and experimental methods, and will address the following:

- Characterization of cultural materials including their resistance to environmental factors
- condition assessment including pollution past and present, natural weathering, pollutant transport, and deposition
- kinetic studies of heterogeneous reactions at material-atmosphere interface, indoor-outdoor pollutant relationships for museums, archives, etc.
- microclimate studies
- development of appropriate non-destructive assessment methods.

2. Scientific and technical support of conservation, restoration, and maintenance.

The aim is to improve the scientific and technical basis of conservation and restoration practice in response to environmental deterioration, including episodic events affecting the mechanical stability of monuments. Projects will focus, in particular, on the development of scientifically valid criteria, standards and technologies, and may include:

- Establishment of criteria and standards for evaluation of conservation and restoration materials and practices
- development of screening strategies for the quality control of conservation materials
- development of integrated conservation techniques and methods for matching treatment to specific material and environmental conditions, including retrospective studies on the effectiveness of previous treatments.

Within the framework of both topics, the design and operation of a mobile laboratory may be proposed, in order to provide support for field research.

3. Environmental archaeometry.

The aim is to develop and apply innovative methods for estimating environmental conditions experienced by cultural heritage items in the past. Research Projects may include:

- Development of new or improved methods for the estimation of historic pollutant levels and of associated damage
- reconstruction of past environmental conditions by a combination of environmental archaeometric measurements, historic data, and modeling.

The routine application of existing methods to studies of technique, provenance, and dating of artifacts is not eligible for support.

4. Socio-economic and policy issues.

The aim is to support incorporation of scientific and technical knowledge into the formulation of environmental policy concerning cultural heritage,.

Proposals may address a range of critical issues in support of the above. The following items are examples for possible inclusion:

- **Establishment of risk and damage patterns for the main categories of relevant materials and cultural property in various regions**
- **cost/benefit evaluations of alternative conservation/preservation strategies and treatments**
- **the development of methods to assess the effects of tourism on cultural property**
- **societal valuation of and response to cultural heritage (e.g. limitations of access to endangered cultural properties, the use of replicas in exhibitions, etc.).**

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1992	Environmental Sciences

4. TITLE AND SUBTITLE
Affordable Environmental Technology: Preparing For the 21st Century

5. FUNDING NUMBERS

6. AUTHOR(S)
Paul Schatzberg

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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European Office
PSC 802 Box 39
FPO AE 09499-0700

8. PERFORMING ORGANIZATION REPORT NUMBER
92-10-R

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ONREUR

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This report is unclassified; distribution is unlimited.

12b. DISTRIBUTION CODE
UL

13. ABSTRACT *(Maximum 200 words)*

In an initial effort to assess environmental research in other countries, the author made selected visits to the United Kingdom, Federal Republic of Germany, the State of Israel, NATO, and the Commission of European Communities in Brussels, Belgium. Results of the author's visits are presented as specific environmental topics such as hydrocarbon bioremediation, groundwater treatment, ordnance demilitarization, marine antifouling control, pollution prevention, with reference to existing Navy requirements and research where relevant. The author points out that research and development has the potential for providing the leverage leading to processess that will achieve affordable cleanup of past, and prevent future environmental insult.

14. SUBJECT TERMS
hydrocarbon bioremediation, groundwater treatment, ordnance demilitarization, marine antifouling, pollution prevention

15. NUMBER OF PAGES
74

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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